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THE UNIVERSITY OF ALBERTA

ATTENTION DEMANDS OF VISUAL WORD RECOGNITION

BY

CHRIS MICHAEL HERDMAN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

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FALL 1987

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ABSTRACT

The purpose of the present research was to directly assess the attention demands associated with recognition of visually presented words. Five experiments were conducted, all of which used a dual-task, change, paradigm. The first three experiments show that (a) attention is required to recognize words within the context of the lexical decision task, (b) the attention demands of word recognition vary with word frequency, and (c) attention demands in the lexical decision task are controlled. In Experiments 4 and 5, attention demands of word recognition were assessed within the context of a word pronunciation task. The results of these experiments show that although attention is required to recognize words in the pronunciation task, these demands cannot be characterized as controlled processes. The findings of the present research are interpreted within the verification model of word recognition and it is suggested that lexical assess is best defined as a mandatory process.

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INTRODUCTION

Several current theories of reading include the assumption that the attention demands associated with word recognition are sources of individual differences in reading (e.g., Frederiksen, 1978, 1981, 1982; LaBerge & Samuels, 1974; Perfetti, 1985; Perfetti & Roth, 1981; Stanovich, 1980, 1981; see also Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Palmer, Macleod, Hunt, & Davidson, 1985). Although many researchers have investigated automatic and strategic activation in lexical memory (e.g., den Heyer, 1986; den Heyer, Briand, & Dannenbring, 1983; Fischler & Bloom, 1979; Fischler & Goodman, 1978; Neely, 1976; Ratcliff & McKoon, 1981a, 1981b; Schvaneveldt & McDonald, 1981; Tweedy & Lapinski, 1981; Tweedy, Lapinski, & Schvaneveldt, 1977), very little research has directly examined the attention demands associated with visual word recognition, per se.

There exists, however, various sources of indirect evidence suggesting that attentional resources are required to recognize visually presented words. This evidence is found in research relating reading skill to independent measures of lexical access (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Curtis, 1980; Hogaboam & Pellegrino, 1978;

Hogaboam & Perfetti, 1978; Perfetti & Lesgold, 1979), as well as in research showing the effects of attentional factors on contextual priming (Parkin, 1979, Smith, 1979; Smith, Theodor, & Franklin, 1983) and on Stroop effects (Kahneman & Chajczyk, 1983; Kahneman & Henik, 1981; Lowe & Mitterer, 1982). The goal of the present research was to provide a direct assessment of the attention demands associated with recognizing visually presented words. In this section, previous research findings suggesting that attentional processes are involved in word processing are discussed and an overview of the present research is given.

Evidence for Attentional Demands in Word Processing

It has been suggested that the development of reading ability coincides with a change in mental processes from being "controlled" to being "automatic" (Curtis, 1980; LaBerge, 1973; LaBerge & Samuels, 1974; Wolf, Bally, & Morris, 1986). Controlled processes are defined as those that occur relatively slowly, must be activated intentionally, and demand resources from a limited capacity supply. In contrast, automatic processes are defined as those that occur rapidly, do not require intention to be activated, and are not demanding of attentional resources (Hasher & Zacks, 1979; LaBerge, 1975, 1981; Logan, 1979,

1980; Posner, 1978; Posner & Snyder, 1975a, 1975b; Schneider and Shiffrin, 1977; Shiffrin & Schneider, 1977).

In contrast to the notion that reading becomes automatized, it has been found that reading performance is affected by attentional factors. For example, it has been shown that even skilled readers find it difficult to time-share between reading and a second, relatively simple task such as monitoring for an auditory probe (Britton, Glynn, Meyer, & Penland, 1982; Britton, Westbrook, & Holdredge, 1978; see also Hirst, Spelke, Reaves, Caharack, & Neisser, 1980). It is not clear, however, which of the many processes activated during reading require attention. One suggestion has been that accessing representations in lexical memory involves attention (Becker, 1976). This concept has been incorporated as a basic assumption into several theories of reading (e.g., see Frederiksen, 1981, 1982; LaBerge & Samuels, 1974; Perfetti, 1985; Perfetti & Roth, 1981; Stanovich, 1980, 1981; see also Baddeley et al, 1985; Palmer et al, 1985). For example, in Perfetti's verbal efficiency theory (Perfetti, 1985; Perfetti & Roth, 1981) efficiency of lexical processing is presumed to determine the availability of resources for other local processes, such as propositional encoding. In this view,

efficiency of lexical access translates into resource demands such that increased efficiency means that fewer resource are required.

Perfetti (Perfetti, 1985; Perfetti & Roth, 1981) suggests that individual differences in reading skill may arise at the level of lexical processing. This assumption is supported by research in which reading skill has been related to performance on tasks that include components of lexical access. For example, reading ability has been related to performance on tasks such as visual matching (Hogaboam & Perfetti, 1978), matching auditorily and visually presented words (Perfetti & Lesgold, 1979), lexical decision (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985), and pronunciation (Curtis, 1980; Hogaboam & Pellegrino, 1978). However, while these studies suggest a relationship between efficiency of lexical access and reading skill, they do not directly relate the attention demands of lexical access to individual differences in reading skill. Moreover, the assumption that attentional resources are required to access lexical representations has not been addressed in these investigations.

Attentional Processes and Contextual Priming

Attentional processes have been studied extensively in

the literature concerned with the effects of contextual priming on word recognition. The procedure used in many priming studies has entailed the presentation of a priming stimulus followed by a target stimulus to which subjects are required to make a lexical decision (word - nonword decision) (Becker, 1979, 1980; de Groot, Thomassen, & Hudson, 1982; Fischler, 1977a, 1977b; Fischler & Bloom, 1979; Fischler & Goodman, 1978; Lorch, 1982; Meyer & Schvaneveldt, 1971; Neely, 1976, 1977; Ratcliff & McKoon, 1981a; Schuberth & Eimas, 1977; Stanovich & West, 1979, 1981, 1983; Tweedy & Lapinski, 1981; Tweedy, Lapinski, & Schvaneveldt, 1977). The basic finding has been that when compared to a neutral or an unrelated condition, processing of target words is facilitated if the prime and target stimuli are associatively related.

Much of the research on contextual priming has focused on facilitation effects due to automatic processes. One explanation of automatic priming effects is based on a spreading activation model of memory (Collins & Loftus, 1975). In accord with the spreading activation model, presentation of a prime results in the activation of a node corresponding to that word in memory. In turn, activation from that node spreads via associative links to partially

activate other related concepts. Contextual priming facilitates lexical decisions to related targets because activation spreads from the prime node to the target node, thereby reducing the amount of target-driven activation needed for a lexical decision to occur.

One implication of the priming research is that words are processed automatically (i.e., without intention and without resource demand) to a level at which semantic relations with other words are represented (Neely, 1977). In this view, contextual priming effects are presumably not affected by conscious changes in subjects' allocation of attentional resources. This notion is supported by research in which it was found that instructions designed to increase the salience of the relation between primes and targets did not affect the magnitude of priming effects (Fischler, 1977b). Other research, however, has shown that responses to target words are dependent not only on the presence or absence of a semantically related prime, but also on the probability that prime and targets are related. For example, Tweedy, Lapinski, and Schvaneveldt (1977) found that when this probability is high, the priming stimulus has a much greater facilitory effect then when the probability is low. Their results suggest that subjects place more

reliance on the semantic information provided by the prime when conditions are such that this information tends to be useful in determining the identity of the target word. More specifically, the results show that "automatic" priming effects are affected by strategic factors.

The influence of strategic factors on effects presumed to reflect automatic priming also has been demonstrated by research in which subjects are required to perform different tasks on the priming stimulus. For example, Parkin (1979) (see also Smith, 1979; Smith et al., 1983) presented a prime followed by a target word and had subjects name the colour of the target ink. In one condition subjects were required to perform a semantic judgment on the prime word. In another condition a nonsemantic (phonemic) judgment was performed on the prime word. On half of the trials primes were related to the targets and on the other half they were unrelated.

The results of the Parkin (1979) study showed that colour naming of the target word ink in the semantic condition was slower when the prime was related to the target as compared to when they were unrelated. Parkin suggests that this finding reflects Stroop-like interference where the lexical representation of the target word was

activated by the related prime, thereby making it more difficult to ignore. In contrast to the semantic condition, interference effects in the nonsemantic condition did not vary between the related and unrelated conditions. Therefore, the results of Parkin's (1979) study show that the way in which primes are processed can effect associative priming.

In summary, research has shown that strategic factors can influence effects that are presumed to reflect automatic processing in contextual priming paradigms. Insofar as changes in processing strategy imply changes in allocation of attentional resources (Kahneman, 1973; Navon & Gopher, 1979, 1980; Norman & Bobrow, 1975), this research suggests that the activation of representations in lexical memory may be dependent upon attention.

Attentional Processes and Stroop Interference

Evidence that attentional resources are required during word processing has also been reported in research using the Stroop task. In the Stroop (1935) colour word task, subjects are required to name the ink colour in which a word is printed. The identity of the words are to be ignored by selectively attending to the colour of the ink. A neutral condition is usually included in which either a colour patch

or a row of colored x's are presented instead of a word. In the compatible condition, the colour name of the word matches the ink colour (e.g., the word "red" printed in red ink). Responses to ink naming in the compatible condition are typically faster as compared to the neutral condition. In the incompatible condition the colour name of the word and the ink colour do not match (e.g., the word "red" printed in green ink). Ink naming responses in the incompatible condition are typically slower compared to responses in the neutral condition.

One interpretation of the Stroop facilitation and interference effects is that the encoding of word identity is automatic insofar as it occurs without intention (Posner, 1978; Posner & Snyder, 1975b). In this view, automatic encoding of word identity facilitates ink naming in the compatible condition by decreasing the amount of input (i.e., colour information) necessary for activating the verbal label associated with the ink colour. In the incompatible condition, word identity interferes with the selection (either during activation or during response output) of the verbal label associated with the ink colour.

According to a strict definition of automaticity, however, the encoding of words in the Stroop task should not

demand attentional resources. In this view, processing of words should not be affected by the concurrent processing of other stimuli. This assumption has recently been challenged by research showing that Stroop effects are affected by the concurrent processing of other stimuli. For example, Kahneman and Chajczyk (1983) (see also Lowe & Mitterer, 1982) had subjects name the colour of a colour patch that was presented at fixation. In one condition the colour patch was accompanied with a word presented either above or below the fixation point. In another condition two words were presented, one on either side of fixation. The words that were presented were either colour words or neutral words. Kahneman and Chajczyk (1983) found that presentation of a single word resulted in both substantial facilitation and interference effects, thus replicating the typical Stroop effects. In the two-word condition, in which both a colour word and a neutral word were presented, facilitation and interference effects were still obtained but they were significantly reduced from the single word condition.

One explanation of the Kahneman and Chajczyk (1983) results is that the processing of words in the Stroop task demands attentional resources. In this view, processing of word identity in the single word condition had access to the

full complement of attentional resources. This resulted in strong activation of word identity which in turn resulted in substantial Stroop facilitation and interference effects. In the two-word condition, the colour word and the neutral word competed for a limited supply of attentional resources. Accordingly, the strength of activation of the identity of the colour word was less as compared to activation in the single word condition, thus resulting in diluted Stroop effects.

An attentional interpretation of the Kahneman and Chajczyk (1983) results, however, is equivocal. For example, an alternative explanation is that the presence of the neutral word in the two-word condition resulted in reduced response competition because on some proportion of the trials subjects attended to the neutral and not the colour word (Humphreys, 1985). This explanation is supported by the finding that Stroop interference effects were reduced more than facilitation effects. However, the Kahneman and Chajczyk (1983) findings are suggestive that attentional resources are involved in word processing.

To summarize, the role of attentional processes in word processing has been implied in research relating reading skill to measures of lexical access. In addition, evidence

suggesting that attention is required to access lexical representations has been reported in selected studies in the contextual priming and the Stroop literatures. This evidence, however, is indirect insofar as the involvement of attentional resources can only be inferred.

Attention Demands of Word Recognition

A direct examination of the attention demands of word recognition has been reported by Becker (1976). Becker's (1976) research centered around his verification model (Becker, 1976, 1979, 1980, 1985; Becker & Killion, 1977; Eisenberg & Becker, 1982) of visual word recognition. The verification model is outlined below and Becker's (1976) research is reviewed.

According to Becker (1976, 1979, 1980, 1985; Becker & Killion, 1977; Eisenberg & Becker, 1982), visual word recognition consists of sensory-feature extraction and verification. Feature extraction results in the specification of a set of candidate words that are consistent with the gross sensory characteristics of the stimulus. In verification, a single lexical unit is selected from the candidate set and a complete representation of the word is generated by combining the relational information stored with that unit with the

primitive features identified in the extraction process. This constructed representation is compared to the item's representation in sensory memory. Recognition occurs when a successful match is made between the constructed and sensory representations. If a match is not made, then the next candidate is selected for verification. The order in which items are selected from the candidate set and submitted for verification is determined, in part, by word frequency: that is, high-frequency words are selected first, and therefore are verified in fewer cycles than are low-frequency words.

Becker (1976) assumes that the verification stage is the locus of attention demands in visual word recognition such that each verification cycle requires a certain amount of attention. Because the order in which items are submitted for verification is determined by word frequency, recognition of high-frequency words should require less attention (i.e., fewer attention demanding verification cycles) than recognition of low-frequency words.

To test this assumption, Becker (1976) had subjects perform a lexical decision task and an auditory probe task concurrently. The primary index of the attention demands associated with lexical processing was a complexity measure (Karlin & Kestenbaum, 1968): the difference in response

times to auditory probes during simple versus choice conditions. Because the choice task requires more attentional resources than the simple task, it was expected that the choice task would be affected more by the capacity requirements of word recognition. Becker (1976) found an interaction of task complexity and word frequency: The complexity effect was small during high-frequency trials but large during low-frequency trials. These results suggest that (a) word recognition requires attentional resources and (b) more attentional resources are required to recognize low- than high-frequency words.

Becker's (1976) research provides the only direct assessment of the resource demands of visual word recognition. As Becker (1976) indicates, however, a potential methodological problem with his study is that subjects were required to execute lexical decision responses before making responses to the auditory probe task. Because lexical decisions are typically slower to low- than to high-frequency words (Dobbs, Friedman & Lloyd, 1985; Scarborough, Cortese, & Scarborough, 1977; Whaley, 1978), the time between presentation of a probe and a subsequent probe-response was longer during low- than high-frequency trials. Thus, it is difficult to determine whether

differences in performance between the simple and choice tasks (i.e., the complexity effect) were due to a limitation in attentional capacity, as Becker concludes, or were caused by differential loss of the tone memory trace during the variable time delay. Loss of sensory information could potentially be more detrimental to performance on the choice task. The longer retention interval imposed by the increased response time to low-frequency words increases the probability that sensory information could decay. This may have resulted in (or at least contributed to) the interaction between word frequency and the type of probe task.

Overview of the Present Research

Evidence suggesting that attentional resources are required during word processing has been reported in selected research in the reading (e.g., see Perfetti, 1985), contextual priming (Parkin, 1979; see also Smith, 1979; Smith et al, 1983) and Stroop (Kahneman & Chajczyk, 1983) literatures. The most direct evidence for the involvement of attentional resources in word processing, however, is provided by Becker's (1976) dual-task investigation of attentional demands in the lexical decision task. In light of the methodological concerns in Becker's (1976) study, and

considering the implications of this research for theories of word recognition (Becker, 1976; Morton, 1982) and reading (Perfetti, 1985; Perfetti & Roth, 1981), it is important to investigate further the attention demands of word recognition.

In the present research the attention demands associated with recognizing visually presented words were directly assessed using a variant of a dual-task paradigm called a change paradigm (Logan, 1985; Logan & Burkell, 1986; Logan & Cowan, 1984). In the typical dual-task paradigm, such as the one used by Becker (1976), subjects are presented with two stimuli and are required to make two responses. In the change paradigm, a secondary task stimulus is paired with a primary task stimulus on some proportion of the dual-task trials. When a secondary task stimulus is presented subjects are required to inhibit a response to the primary task stimulus and make an overt response only to the secondary stimulus. Decrements in performance on the secondary task are interpreted as reflecting the resource requirements associated with processing of the primary stimulus.

The change paradigm has been used to separate response competition and capacity interpretations of dual-task

performance (Logan, 1985; Logan & Burkell, 1986; Logan & Cowan, 1984). Previous research using the change paradigm has suggested that response competition may produce more interference than does competition for attentional resources (Logan, 1985). However, because this research has only employed restricted stimulus sets and task domains, it is premature to concluded that interference does not occur due to limitiations in the availabilty of processing resources. Accordingly, the present research is based on the assumptions that (a) interference may arise as a result of competition for attentional resources (Kahneman, 1973; Kerr, 1973; Norman & Bobrow, 1976; Navon & Gopher, 1979) and (b) that the change paradigm provides a way to assess attention demands. Clearly a distinct advantage of the change paradigm over the dual-task paradigm used by Becker (1976) is that the amount of time between presentation of a secondary stimulus and a subsequent response to that stimulus would not depend upon time to execute a response to a primary stimulus.

With the exception of Becker (1976), theories of word recognition have not included attentional processes (e.g., Forster, 1976; Gordon, 1983; Morton, 1969, 1970; Paap, et al, 1982). Because the locus of attention demands during

word recognition has been explicitly outlined by Becker (1976), the verification model was used as a conceptual framework for the present investigations.

Five experiments are reported, all of which implement the dual-task change paradigm. The first three experiments assessed the attention demands of word recognition within the context of a lexical decision task. In accord with the verification model, Experiment 1 provides evidence that (a) attentional resources are required to recognize words and (b) resources are required for a longer period of time to recognize low- than high-frequency words. These findings serve as the foundation on which the following experiments are based. The second experiment was conducted to address a potential methodological problem inherent in the procedure used in Experiment 1. The results of this experiment validate the procedure used in Experiment 1 and throughout the following experiments. The third experiment was used to examine the effects of resource allocation factors on word processing in the lexical decision task. The results of this experiment suggest that determining the lexicality of words in the lexical decision task requires controlled processes.

The fourth and fifth experiments provide assessments of the attention demands of lexical access by examining word

processing in the context of a pronunciation task. The results of Experiment 4 generally parallel those found using the lexical decision task (i.e., Experiments 1 - 3) and suggest that (a) lexical access requires attentional resources and (b) more resources are required to access representations of low- than high-frequency words. Experiment 5 extends the examination of the demands of lexical access in the pronunciation task. The results of Experiment 5 shows that lexical access satisfies the criteria of neither automatic nor controlled processes. It is suggested that lexical access is best characterized as a mandatory (Herdman & Friedman, 1985; Navon & Gopher, 1979) process.

EXPERIMENT 1

In the first experiment the attention demands of recognizing visually presented words were assessed in the context of a lexical decision task. Subjects performed a lexical decision task and an auditory probe task alone and in combination. On 75% of the dual-task trials auditory probes were not presented. On these trials subjects were required to make lexical decision responses. On the remaining dual-task trials auditory probes were presented and subjects were to inhibit lexical decision responses and make a probe response. These trials represent the change (Logan & Burkell, 1986) component of the dual-task.

Capacity demands during word recognition should limit the amount of resources that are available to concurrently detect and respond to auditory probes. This should result in single- to dual-task performance decrements on the probe task. Moreover, because the resource requirements of verification presumably vary with word frequency (Becker, 1976), fewer resources should be available for the probe task during concurrent processing of low- as compared to high-frequency words. This should be reflected in larger performance decrements on the probe task during low- as compared to high-frequency trials.

To assess attention demands at various points during the word recognition process, the SOA between presentation of a letter string and an auditory probe was varied. Two intervals were used: 0 and 167 ms. On the assumption that verification begins very soon after presentation of a letter string, the lexical decision task should require resources early in the processing sequence. Moreover, because all letter strings (i.e., regardless of frequency) must be verified to some extent, there should be little or no evidence for differential capacity requirements between high- and low-frequency words when assessed at the 0 ms SOA. Therefore, equivalent performance decrements on the probe task are predicted during low- and high-frequency trials. However, because fewer verification cycles are required to recognize high-frequency words (Becker, 1976), at the 167 ms SOA, resources should be required for a shorter period of time to recognize high- as compared to low-frequency words. This should be reflected in smaller performance decrements on the probe task during high-frequency trials in the 167 ms than the 0 ms SOA condition. Based on the assumption that unfamiliar words are still being verified at the time a probe is presented in the 167 ms SOA condition, decrements in probe performance should not vary across SOA during

low-frequency trials.

It is likely that subjects reserve a portion of their total capacity in the dual-task condition in anticipation of a probe. Accordingly, fewer resources should be available for lexical decision performance in the dual- than in the single-task condition. This should result in single- to dual-task performance decrements on the lexical decision task. Moreover, because recognition demands presumably last longer for low- than for high-frequency words, it was expected that decrements in lexical decision performance would be larger during low-frequency trials.

The primary measure of lexical decision and probe task performance is reaction time. Performance decrements should be reflected in longer latencies in the dual- than in the single-task condition.

Method

Subjects

Twenty undergraduate students participated in partial fulfillment of a course requirement.

Apparatus

A MicroTech Unlimited laboratory computer was used to present letter strings on a Panasonic video monitor (Model WV-5300), generate the probe tones (1000 hz) over a pair of

Pulsar headphones (Model MD-802B), and to record responses and latencies. Subjects were seated in a darkened chamber approximately 50 cm in front of the video monitor. The longest stimuli (seven letters) were 4 mm high X 14 mm long. A response panel was located vertically in front of the subjects. It contained three keys, one located at the center of the panel, one 8 cm above center, and another 8 cm below center. The center key was used to start trials and to make lexical responses, the upper key was pressed when an auditory probe had been detected, and the lower key was used to signal the end of the trial. Subjects were instructed to make all key presses using the index finger of their preferred hand.

Procedure

Subjects were randomly assigned to one of the two SOAs (0 and 167 ms). The experiment was run across two days, one session per day. Each session took approximately 55 minutes. The Day 1 session was divided into three blocks of trials: practice, single-task, and dual-task. The Day 2 session consisted of only single-task and dual-task blocks. The practice block consisted of 32 trials of lexical decision, auditory detection, and dual-task practice. The single-task baseline conditions each consisted of 52 (4

practice + 48 experimental) lexical decision and 52 (4 practice + 48 experimental) auditory detection trials. Performance on the single-tasks served as baseline measures for the dual-task trials that followed. The dual-task conditions each consisted of 208 (16 practice + 192 experimental) dual-task trials.

In all conditions, subjects fixated on a centrally presented dot and started trials by pushing and holding in the center key. After 500 ms, the fixation dot disappeared from the screen. In the single-task lexical decision condition, the fixation dot was replaced by a letter string. Subjects were to release the start key if a letter string formed a word and to continue holding the start key in if the letter string formed a nonword. The letter string disappeared from the screen when the center key was released or after 2000 ms had elapsed.

For the single-task auditory probe condition, the fixation dot was replaced by a string of five asterisks. On "no-probe" trials, subjects were to continue holding the center start key in until the next trial was to begin. On "probe" trials, subjects were to release the center key as quickly as possible upon detection of a tone, and then to quickly push the top key.

On dual-task trials subjects fixated, and then started a trial by pushing and holding in the center key. The fixation dot was replaced 500 ms later by a letter string. On "no-probe" trials, subjects were to continue with the lexical decision component of the dual task. On "probe" trials, subjects were to quickly respond to the probe by pressing the top key. That is, when a probe was detected, the lexical decision component of the dual-task was to be forfeited and priority given to making a probe response. Subjects were informed that 75% of the single-task auditory probe and dual-task trials were "no-probe" trials and 25% were "probe" trials.

Lexical decision latency was measured as the time between presentation of a letter string and the release of the start key. Auditory probe latency was measured as the time between presentation of a tone and release of the start key plus the time taken to move the index finger up to push the top key.

Stimulus Materials

There were 32 words and 32 nonwords used in the practice session. Half of each item type were used for single-task lexical decision trials and the remaining items were presented as the dual-task trials. A total of 480 letter

strings (240 words and 240 nonwords) were used in the experiment proper (i.e., single- and dual-task conditions but excluding practice trials). There were an equal number of high- and low-frequency words selected from Kucera and Francis (1967). High-frequency items ranged from words occurring 66 times per million of text to 897 times per million, with a mean of 219.4. The low-frequency words were taken from the one and two per million category with a mean of 1.8. High- and low-frequency words were matched for word length. Nonwords were constructed by changing one letter of real words. Words and nonwords ranged from 4 to 7 letters in length.

The dual-task lexical decision stimuli were arranged into two different sets (A and B) that were random with the restrictions that (a) half the stimuli in each half of a set were words, (b) half the words in each half of a set were high-frequency, (c) no more than three items in a row required the same response (word/nonword), and (d) half of the probe trials in each half of a set occurred when a word was presented, one half of these being high-frequency words. Within each dual-task set, 24 words (12 high- and 12 low-frequency) and 24 nonwords were designated as items to be presented during probe trials. Another 24 words (12

high- and 12 low-frequency) and 24 nonwords were designated as "critical" items which were used to compare dual-task lexical decision latencies (i.e., when a probe was not presented) to single-task lexical decision latencies.

The single-task lexical decision stimuli were also arranged into two sets (A and B). Set A was used as a control baseline for the set A dual-task critical set. Set B single-task stimuli were used as a control baseline for the set B dual-task critical set. Half of the subjects in each SOA condition received set A items and the remaining subjects received set B. Each single-task set consisted of an equal number of high- and low-frequency words. These sets were matched to each other and to their respective dual-task sets for length and for word frequency. Half of the subjects in each SOA condition received set A on Day 1 and set B on Day 2. The remaining subjects received the opposite order.

Results and Discussion

The mean of all correct latencies within each condition were computed for each subject. Latencies greater than 2.5 standard deviations from the mean of the respective condition were defined as outliers, removed from the data set, and the means were recomputed. Removal of outlier

scores did not change the pattern of results. There were no significant effects of stimulus set (A versus B), order, or set by order on either the lexical decision nor the probe data, and so the data were collapsed across this variable. In the following analyses, SOA (0 vs. 167 ms) is a between-subjects factor. Condition (single vs. dual) and Frequency (high vs. low) are within-subjects factors.

Errors on the auditory probe task occurred very seldom (on less than 1% of the trials), did not differ across any factors, and so will not be considered further. Two types of lexical decision errors were possible; those occurring during word trials and those occurring during nonword trials. On word trials, errors occurred when a word response was not made. A 2 (SOA) X 2 (Condition) X 2 (Frequency) analysis of the word data showed that errors were made on a greater percentage of low- than high-frequency trials (9.8% vs. 0.8%), $F(1, 18) = 40.29$, $p < .001$. This indicates that low-frequency words were more often mistaken for nonwords than were high-frequency words. No other effects were significant. Errors on nonword trials occurred when a word response was incorrectly indicated. On the average, this type of error was made on 18.3% of the nonword trials. A 2 (SOA) X 2 (Condition) analysis did not

show any significant effects.

Auditory probe responses

The single- and dual-task auditory probe latencies are presented in Table 1. Because the same single-task probe scores were used as baselines for both high- and low-frequency trials, changes in performance from single- to dual-task conditions were analyzed using decrements scores. Decrement scores were computed by subtracting each subject's single-task scores from the corresponding dual-task scores. A 2 (SOA) X 2 (Frequency) analysis of the decrement data did not show any significant main effects nor interactions. Accordingly, these results are not consistent with Becker's (1976) assumption that recognition demands vary with word frequency.

The failure to obtain evidence for differential recognition demands, however, may reflect the fact that recognition demands were not assessed independently from the demands associated with response output. To separate these

two potential sources of capacity limitations, the total probe measure was divided into two indices. The first, termed Detection latency, was measured as time between presentation of tones until the release of the start key. This measure presumably reflects time to detect and initiate responses to probes (Keele, 1973). A decrease in available capacity during concurrent processing of words should result in longer Detection latencies. The second index of probe responses was Movement latency. This measure reflected time to execute a movement after detection and response initiation had been completed. Movement latency was time between release of the start key and the pushing of the top ("probe") key on the response panel. This measure presumably indexes the availability of response output capacity for executing probe responses. The single- and dual-task Detection and Movement latencies are summarized in Table 1. Decrement scores were computed for the Detection and Movement measures.

A 2 (SOA) X 2 (Frequency) analysis of the Detection decrement data showed a main effect of Frequency where performance decremented more during low-frequency than during high-frequency trials (see panel A of Figure 1), $F(1, 18) = 7.48$, $p < .014$. F-tests for simple effects showed a

significant difference between high- and low- frequency trials only at 167 ms SOA, $F(1, 18) = 9.73$, $p < .01$. Moreover, whereas the amount of decrement during low-frequency trials did not differ across SOA, ($F < 1$), decrements during high-frequency trials were significantly smaller at 167 than at the 0 ms SOA, $F(1, 18) = 9.11$, $p < .01$.

The Detection results indicate that when assessed shortly after presentation, recognition demands did not differ between high- and low-frequency words. When processing demand was assessed after a 167 ms delay, however, more capacity was required by low- than high-frequency words. The pattern of results indicate that capacity was required for a longer period of time to process low-frequency as opposed to high-frequency words. Thus, the Detection data are consistent with Becker's (1976) assumption that more attention-demanding verification cycles are required to recognize low- than high-frequency words.

A 2 (SOA) X 2 (Frequency) analysis of the Movement decrement data did not show any significant effects. However, there was a nonsignificant trend towards larger decrements in Movement performance during concurrent processing of high- than low-frequency words (see panel B of Figure 1), $F(1, 18) = 2.91$, $p = .11$.

Lexical decision responses

The single- and dual-task lexical decision latency data are presented in Table 2. A 2 (SOA) X 2 (Frequency) analysis of the single-task data showed only a reliable effect of word frequency: lexical decision responses were faster to high- than to low-frequency words, $F(1, 18) = 163.18$, $p < .001$. A similar analysis of the dual-task data also only showed a reliable effect of word frequency, $F(1, 18) = 96.43$, $p < .001$. These results replicate the word frequency effect found throughout the literature and suggest that the lexical decision task in the present experiment was comparable to other lexical decision paradigms. No other main effects nor interactions approached significance in these analyses.

A 2 (SOA) X 2 (Condition) X 2 (Frequency) analysis showed that lexical decision latencies were longer in the dual- than in the single-task condition (634 vs. 598 ms) $F(1, 18) = 11.93$, $p < .003$. There was also a reliable effect of word frequency where latencies were longer to low- than to high-frequency words (690 vs. 534 ms) $F(1, 18) = 160.94$, $p < .001$. The three-way interaction of SOA X Condition X Frequency was also reliable, $F(1, 18) = 7.67$, $p < .013$. The pattern of means indicate that during low-frequency trials, single- to dual-task decrements in lexical decision performance were greater in the 167 than in the 0 ms SOA condition, but that during high-frequency trials, performance decrements did not vary with SOA (see panel C of Figure 1). This pattern was confirmed with F-tests for simple effects using the error term from the three-way analysis. Those analyses showed that only the shift in performance during low-frequency trials was reliable, $F(1, 18) = 58.42$, $p < .001$.

The lexical decision results suggest that subjects initially reserved capacity for processing auditory probes in the dual-task condition, but re-allocated resources to the lexical decision task when a probe did not occur. In the 0 ms SOA condition, subjects presumably were able to

re-allocate resources very soon after a trial had started because it was readily obvious when a probe was not going to be presented. In the 167 ms SOA condition, subjects would have been required to wait before concluding that a probe would not be presented. Therefore, resources for the lexical decision task would have been limited for a longer time period in the 167 than the 0 ms SOA condition.

Resource limits resulted in equivalent decrements in lexical decision performance at both SOA conditions during high-frequency trials. On low-frequency trials, resource limits resulted in larger performance decrements at the 167 than the 0 ms SOA condition. In accord with Becker (1976), this suggests that more attention (i.e., over time) is required to verify low- than high-frequency words.

To summarize, the probe Detection and lexical decision results show that attentional resources are required for a longer period of time to recognize low- than high-frequency words. These findings provide support for Becker's (1976) notion that demands associated with recognition vary with word frequency. The probe Movement results show that execution of probe responses was slower in the dual- than the single-task condition. In accord with a capacity interpretation, the Movement results suggest that less

capacity was available in the dual- than in the single-task condition. Capacity limitations during response execution may reflect a general concurrence cost (e.g., Navon & Gopher, 1979) caused by having to coordinate the lexical and probe tasks. An alternative possibility, however, is that performance decrements on the Movement measure reflect Stroop-like response competition between lexical and probe responses. Accordingly, during probe trials lexical decision responses may have inhibited the pressing of the upper response key because responses to probes (lift finger and move to depress the upper key) differed from responses to words (lift finger and do not move to depress the upper key).

A response competition hypothesis can also account for the trend towards larger decrements in Movement performance during high- than low-frequency trials. That is, because lexical decision latencies vary with word frequency, relatively stronger response competition and thus more inhibition of the conflicting probe response would occur during high- than during low-frequency trials.

The possibility of competition between probe and lexical responses in the dual-task condition raises the issue of whether Detection latencies were also influenced by response

factors. This is of particular concern because the response requirements of the lexical decision task and the initial response component of the auditory probe task both involved releasing the center "start" key. Because of this, it is possible that in the dual-task condition probe responses were facilitated by lexical decision responses. Moreover, time to complete verification presumably varies with word frequency (Becker, 1976, 1980, 1985). Therefore, probe responses may have been facilitated more during high- than during low-frequency trials. In this view, the observed interaction of word frequency and decrements in Detection performance may reflect the fact that less activation from a probe stimulus was necessary to execute the first component of the probe response during concurrent processing of high-as compared to low-frequency words.

Probe responses were not required (nor were probe tones presented) during lexical decision trials in the dual-task condition. Therefore, neither a response competition nor a response facilitation hypothesis can address the SOA X Condition X Frequency interaction in which decrements in lexical decision performance interacted with SOA during low-but not during high-frequency trials (panel C of Figure 1). In addition, it should be noted that the response

facilitation hypothesis may not provide a complete account of the probe Detection data in that "facilitation" should have resulted in faster, not slower latencies in the dual-than in the single-task condition. However, it is possible that decrements in Detection performance resulted from a general limit in capacity due to some form of concurrence cost (Navon & Gopher, 1979) and that the observed interaction with word frequency reflected differential facilitation of probe responses. In any case, it is evident that in order to obtain a clearer understanding of the attention demands of word recognition it is necessary to disambiguate the response requirements of the lexical and probe tasks.

EXPERIMENT 2

In the second experiment, the response requirements of the lexical decision task and the probe tasks were separated by having subjects elicit verbal instead of manual responses in the lexical decision task. In addition, lexical responses were only required on nonword trials. On word trials subjects were not to make an overt lexical decision response. Responses to auditory probes were executed as in Experiment 1, and the same change paradigm was implemented.

Probe responses were divided into the Detection and Movement measures used in Experiment 1. In accord with a response facilitation hypothesis, probe Detection performance should not be affected by concurrent lexical processing of words because the response requirements of the tasks do not overlap. Therefore, in contrast to the findings of Experiment 1, a response facilitation hypothesis predicts that Detection performance should not differ across single-to dual-task conditions. Moreover, should decrements in Detection performance occur (e.g., due to concurrence cost), they should not interact with word frequency. According to a capacity notion, however, Detection latencies should reflect the attention demands of recognizing words in the lexical decision task. In this view, Detection

performance is predicted to decrement from single- to dual-task conditions. Moreover, because the demands of recognition presumably vary with word frequency (Becker, 1976), decrements in Detection performance should be greater during low- than during high-frequency trials.

Because lexical responses were not required during word trials, competition between lexical and probe responses should not exist. Therefore, a response competition hypothesis predicts that Movement performance should not differ across single- to dual-task conditions. However, to the extent that the decrements in Movement performance in Experiment 1 represent a general concurrence cost, decrements in Movement performance will be found.

Evidence for differences in the processing demands of high- and low-frequency words were obtained in Experiment 1 only when subjects were probed at 167 ms SOA. For that reason, only the 167 ms SOA condition was included in the second experiment. Also, to increase the overlap in demand for attentional resources, the probe task was changed from a simple detection task to a choice task. For the choice probe task two tones were used that differed in pitch. The higher pitched tone was designated as the probe and the lower tone as a distractor.

Method

Subjects

Eight undergraduate students participated in partial fulfillment of a course requirement.

Apparatus and stimuli

The same response panel as described in Experiment 1 was used. A Grason-Stadler model E7300A-1 voice activated relay (VOR) was interfaced with the computer to record lexical decision responses. The stimuli were the same as those used in Experiment 1.

Procedure

Each subject participated in one session. Half of the subjects received set A stimuli and half received set B stimuli. Sessions were divided into three blocks of trials as described in Experiment 1. Trials were initiated, as in Experiment 1, by pushing and holding in the center key on the response panel. For the single-task lexical decision condition, the fixation dot was replaced 500 ms later by a letter string. Subjects were to say "nonword" if the letter string formed a nonword. No response was required when a word was presented. The letter string disappeared from the screen when a lexical ("nonword") response had been made or after 2000 ms had elapsed. The center key was held in

throughout each trial. At the end of a trial, the subject pushed the key located at the bottom of the response panel and prepared for the next trial.

Single-task auditory probe trials proceeded as described in Experiment 1, except that on 25% of the trials a distractor tone was presented. Subjects were instructed to treat "distractor" trials like "no-probe" trials by continuing to hold in the center key until 2000 ms had elapsed and the next trial was to begin. Probe tones were 625 hz, distractor tones were 313 hz.

In the dual-task condition, subjects were to continue holding in the center key during "no-probe" and "distractor" trials and to proceed with the lexical decision component of the dual-task. That is, they were to say "nonword" if the letter string formed a nonword, but to make no response if it formed a word. On "probe" trials subjects were to forfeit the lexical decision component of the dual-task and to quickly make a probe response.

Results and Discussion

Outliers were defined as described in Experiment 1 and removed from the data set. Removal of outlier scores did not change the pattern of the results. There were no reliable effects of stimulus set (A versus B), so the data

were collapsed across this variable. All factors in the following analyses are within-subjects. Because lexical responses were not made to word stimuli, the lexical decision data were not considered further.

Auditory probe responses

Latencies. Auditory probe latencies are shown in Table 1. The Detection and Movement were converted to decrement scores as described in Experiment 1. Separate analyses were performed on the Detection and Movement data. A one-way analysis of the Detection decrement data showed that single-to dual-task decrements in Detection performance were greater during low-frequency than during high-frequency trials (250 vs. 234 ms), $F(1, 7) = 9.78$, $p < .017$. Therefore, the Detection results are consistent with those reported in Experiment 1 and show that more capacity was required to recognize low- than high-frequency words.

A one-way analysis of the Movement decrement data was not significant. Therefore, the Movement results differ from those reported in Experiment 1 and it is concluded that the trend towards differential decrements in Movement performance observed in Experiment 1 resulted from competition between lexical decision and probe responses.

Errors. Subjects missed responding to a probe tone on

less than 4% of the trials. This type of error did not differ across factors. Errors on distractor trials occurred when a probe response was made mistakenly. This type of error was more frequent in the dual- than the single-task condition (17.2% vs. 7.2%), $F(1, 7) = 7.54$, $p < .029$, suggesting that less capacity was available to perform the probe task in the dual-task condition.

To summarize, separating the response requirements of the lexical decision and probe tasks resulted in the same pattern of Detection results as those reported in the 167 ms SOA condition of Experiment 1. Therefore, the findings disconfirm a response facilitation explanation which predicted that Detection performance would neither vary across single- to dual-task conditions nor interact with word frequency. In accord with Becker (1976), it is concluded that (a) recognition of words requires attentional capacity and (b) more attention is required to recognize low- frequency as compared to high-frequency words.

EXPERIMENT 3

One of the defining characteristics of controlled processes is that they require attentional resources (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The results of Experiments 1 and 2 show that recognition of visually presented words requires attentional resources and in this sense word recognition can be characterized as a controlled process. Because controlled processes require attentional resources, they are assumed to be affected by strategic factors such as the allocation of resources toward other tasks. In accord with this assumption, allocation of resources to the probe task in Experiment 1 resulted in single- to dual-task decrements in lexical decision performance. These decrements varied with word frequency presumably because recognition is more resource dependent (i.e., dependent on resources for a longer period of time) during processing of low- than high-frequency words.

The goal of the present experiment was to provide a further test of the assumption that recognition is affected by strategic factors. To do this, the resource demands of the probe task were manipulated by varying task difficulty. In the simple condition subjects were required to indicate when they heard an auditory probe tone. In the complex

condition, subjects were required to discriminate between two tones. It was assumed that more resources are required in the complex- than in the simple-probe condition because the former includes extra cognitive (i.e., decision) processes.

In accord with resource theory (Kahneman, 1973; Norman & Bobrow, 1975), when total capacity is exceeded, tasks that compete for resources will show shifts in performance with changes in the resource demands of one or the other task. In this view, increasing the resource demands of the auditory probe task should increase the extent to which the probe task and the lexical decision task compete for resources. Increased competition for resources should result in larger single to dual-task performance decrements.

Probes were presented at 167 ms (SOA) after the presentation of letter strings. When assessed at this SOA, the demands of word recognition are assumed to vary with word frequency because verification of high-frequency words presumably is complete whereas verification of low-frequency words is still ongoing. Accordingly, overlap in demand for resources between the lexical decision task and the probe task will be great during low-frequency trials, but will be minimal during high-frequency trials. Therefore, on

low-frequency trials, lexical decision and probe task performance should decrement from single- to dual-task conditions. These decrements should be larger in the more resource demanding, complex-probe condition than in the simple-probe condition. During high-frequency trials, only small decrements in performance are expected. If these decrements are due to overlapping resource demands, then shifts in performance should also occur but these shifts should be minimal. If, on the other hand, decrements during high-frequency trials occur because of concurrence cost (e.g., Navon & Gopher, 1979), then shifts in performance may not be observed.

Auditory probe responses were divided into the Detection and Movement measures used in the previous experiments. Because the processes affected by the difficulty manipulation (i.e., decision processes) are indexed with the Detection measure, it was assumed that the manipulation of probe-task difficulty would be reflected in changes in Detection performance. The response requirements of the probe task were the same in the simple as in the complex condition. Therefore, the amount of interference between lexical and probe responses should not vary across simple-and complex-probe conditions. Accordingly, decrements

on the Movement measure were not predicted to vary with task difficulty.

Method

Subjects

Sixteen undergraduate students participated in this study to partially fulfill a course requirement.

Apparatus and Stimuli

The apparatus and stimuli were the same as described as Experiment 1.

Design

Subjects participated in two sessions run on consecutive days. Each session consisted of a practice, a single-task, and a dual-task block. In the practice condition subjects performed 32 trials of lexical decision, auditory detection, and dual-task practice. The single-task baseline condition consisted of 52 (4 practice + 48 experimental) lexical decision trials and 52 (4 practice + 48 experimental) auditory detection trials. The dual-task conditions consisted of 208 (16 practice + 192 experimental) trials of combined lexical decision and probe task.

Procedure

In all conditions a fixation dot was presented centrally and subjects started trials by pushing and holding in the

center key. The fixation dot disappeared after 500 ms. In the single-task lexical decision condition the fixation dot was replaced by a letter string. Subjects were instructed to release the center key as quickly as possible if the letter string formed a word but to continue holding the center key in if the letter string formed a nonword. The letter string disappeared from the screen when the center key was released or after 2000 ms had elapsed.

In the single-task auditory probe condition, the fixation dot was replaced by a string of five asterisks. In both the simple and complex conditions a probe-tone (625 hz) was presented on 25% of the trials. On 75% of the simple condition trials, no tone was presented. In the complex condition, a distractor tone (331 hz) was presented on 25% of the trials and no tone was presented on 50% of the trials. On no-tone and distractor trials subjects were to continue holding in the center key. On probe trials, the center key was to be released and the top key pushed as quickly as possible.

In the dual-task condition, letter strings were presented on all trials, but tones (i.e., either probe or distractor) were presented only on 50% of the trials. In the complex condition, on trials during which either no tone

or a distractor tone was presented, subjects were to continue with the lexical decision component of the dual-task. On probe trials, the lexical decision component of the dual-task was to be forfeited and priority given to the probe task. That is, they were to release the center key and push the top response key as quickly as possible.

Tones (i.e., probe and distractor) were presented 167 ms following onset (i.e., 167 SOA) of the asterisks in the single-task auditory probe condition. The same SOA was used in the dual-task condition. Lexical decision latency was time between presentation of words and release of the center key. Probe Detection latency was time between presentation of probe-tones and release of the center key. Probe Movement latency was time between release of the center key and pushing of the top key. Order of condition (simple vs. complex) and stimulus set were counterbalanced across subjects.

Results and Discussion

Latencies which were more than 2.5 standard deviations from the mean of their respective condition were defined as outliers, removed from the data set, and the means were re-calculated. A total of 3.8% of the probe scores and 5.1% of the lexical decision scores were defined as outliers.

Removal of outlier scores did not change the pattern of results. Difficulty (simple vs. complex), Condition (single-vs. dual-task), and Frequency (high- vs. low-frequency) are all within-subjects.

Auditory probe responses

Latencies. The single- and dual-task Detection and Movement latencies are summarized in Table 3. Decrement scores were computed as described in Experiment 1. Separate analyses were performed on the Detection and Movement data. A one-way analysis of the single-task Detection latencies showed that Detection latencies were longer in the complex than the simple condition (335 vs. 257 ms), $F(1, 15) = 22.61$, $p < .001$. This finding is consistent with the assumption that the probe-difficulty manipulation had the desired effect of increasing the demands of processes (e.g., decision) indexed by the Detection measure.

A 2 (Difficulty) X 2 (Frequency) analysis of the Detection decrement data showed that Detection performance

decremented from single- to dual-task conditions more during low-frequency than high-frequency trials (decrements of 72 vs. 24 ms), $F(1, 15) = 24.88$, $p < .001$. This finding replicates the Detection results reported in Experiments 1 and 2 and supports the assumption that the attention demands of word recognition vary with word frequency. The interaction of Difficulty X Frequency was also significant, $F(1, 15) = 4.72$, $p < .046$. During high-frequency trials single- to dual-task decrements in performance shifted only slightly from simple to complex conditions (decrements of 26 vs. 22 ms). However, during low-frequency trials decrements were larger in the complex than the simple probe condition (decrements of 90 vs. 52 ms). This pattern was confirmed with planned comparisons which showed a reliable effect of difficulty only during low-frequency trials, $F(1, 15) = 7.71$, $p < .014$, indicating that shifts in performance occurred only during low-frequency trials. The Detection results, therefore, suggest that competition for resources between the lexical decision task and the probe task occurred only during low-frequency trials. The absence of shifts in performance during high-frequency trials suggests that lexical decisions to these words did not require attentional resources at the time of the probe. In this

view, decrements in performance during high-frequency trials represent a form of concurrence cost (Navon & Gopher, 1979).

A one-way analysis of the single-task Movement data was not reliable $F(1, 15) = 3.71$, $p = .073$, indicating that latencies did not vary reliably with task difficulty. Therefore, the manipulation of probe-task difficulty did not substantially change the demands of outputing a probe response.

A 2 (Difficulty) X 2 (Frequency) analysis of the Movement decrement data showed a main effect of Frequency, indicating that Movement performance decremented more during high-frequency than during low-frequency trials (decrements of 130 and 80 ms), $F(1, 15) = 7.38$, $p < .016$. The interaction of Frequency and Difficulty, however, was not reliable, $F < 1$. Therefore, single- to dual-task decrements in Movement performance did not vary across probe-task complexity.

Errors. Sensitivities to auditory probes were analyzed by converting responses to d' scores. D' scores were used because they provide a way to simplify the examination of performance across experimental conditions. A 2 (Difficulty) X 2 (Frequency) analysis did not show any significant effects.

Lexical decision responses

Latencies. The single- and dual-task lexical decision latencies are summarized in Table 4. In the single-task condition, lexical decision latencies were longer to low-than to high-frequency words (632 vs. 530 ms), $F(1, 15) = 46.94$, $p < .001$. This replicates the word frequency effect reported in Experiment 1 and throughout the literature (e.g., Dobbs, Friedman & Lloyd, 1985; Gordon, 1983; Scarborough, Cortese, & Scarborough, 1977; Whaley, 1978).

The word frequency effect was also obtained in an analysis of the dual-task data (701 vs. 579 ms), $F(1, 15) = 32.34$, $p < .001$. Also, dual-task lexical decision latencies were longer in the complex than the simple condition (658 vs. 627 ms), $F(1, 15) = 5.60$, $p < .032$, suggesting that fewer resources were available for lexical decisions in the more difficult probe condition. Although the Frequency X Difficulty interaction was not reliable, $F(1, 15) = 1.32$, $p = .278$, the means associated with this interaction show that

an increase in probe difficulty from simple to complex conditions had only a negligible effect during high-frequency trials (571 vs. 586 ms), but during low-frequency trials lexical decision latencies were much longer in the complex than the simple condition (792 vs. 683 ms). This pattern was confirmed with planned comparisons using the interaction error term which showed only a significant effect of probe-task difficulty during low-frequency trials, $F(1, 15) = 5.02$, $p < .05$. Therefore, the dual-task data suggest that there was overlap in demand for resources between the lexical decision and probe tasks during low- but not during high-frequency trials.

A 2 (Difficulty) X 2 (Condition) X 2 (Frequency) analysis showed that latencies were longer to low- than to high-frequency words (669 vs. 554 ms), $F(1, 15) = 56.43$, $p < .001$. This finding reflects the word frequency effect reported in the single- and dual-task analyses. Latencies were also longer in the dual-task than the single-task condition (642 vs. 581 ms), $F(1, 15) = 15.95$, $p < .001$, indicating that lexical decision performance decremented from baseline to dual-task trials. No other main effects nor interactions were significant.

Errors. Two types of lexical decision errors were

possible. On word trials errors occurred when subjects failed to make a word response. This type of error was more frequent during low- than during high-frequency trials (6.9% vs. 0.8%), $F(1, 15) = 17.41$, $p < .001$. This finding complements the word frequency effect obtained with the latency data. The second type of error occurred on nonword trials when subjects made a word response. This type of error was more frequent in the dual- than the single-task condition (25.5% vs. 20.8%), $F(1, 15) = 6.11$, $p < .026$. This result supports the assumption that fewer resources were available for the lexical decision task in the dual-task condition.

The lexical decision results suggest that subjects allocated attentional resources to the probe task in the dual-task condition in anticipation of having a tone presented. This resulted in single- to dual-task decrements in lexical decision performance. The dual-task data show that more attention was allocated to the probe task in the complex-probe than in the simple-probe condition. This shift in resource allocation resulted in performance shifts during low-frequency, but not during high-frequency trials. These results suggest that frequency sensitive processes in the lexical decision task are affected by resource

allocation policies.

To summarize, decrements in Detection performance were found to vary with word frequency, indicating that attention demands were greater during recognition of low-frequency than high-frequency words. In accord with Becker (1976), the findings are consistent with the notion that when probed at 167 ms SOA, attention-demanding verification is complete during high-frequency trials but still ongoing during low-frequency trials. The results also showed that shifts in Detection performance across probe-task difficulty only occurred during low-frequency trials. This effect was complemented by the finding that dual-task lexical decision performance varied with probe-task complexity, but also only during low-frequency trials. Based on resource theory (Kahneman, 1973; Norman & Bobrow, 1975), it is concluded that competition for controlled resources between the lexical decision task and the probe task only occurred during low-frequency trials. In a more general sense, the results show that processes which are frequency sensitive in the lexical decision task are affected by strategic factors, and in this view, can be defined as controlled processes.

EXPERIMENT 4

In the Experiments 1 - 3, a lexical decision task and an auditory probe task were combined to assess the demands of recognizing visually presented words. The results showed that (a) word recognition in the lexical decision task is an attention-demanding process, (b) attentional resources are required for a longer period of time to recognize low-frequency than high-frequency words, and (c) frequency sensitive processes in the lexical decision task are affected by resource allocation strategies. These findings are generally consistent with Becker's (1976, 1979, 1980, 1985; Becker & Killion, 1977) model of word recognition in which it is assumed that (a) attentional resources are required to verify words and (b) more attention demanding verification is required to recognize low-frequency than high-frequency words.

Several researchers have argued, however, that the lexical decision task may include extraneous factors that make the task unsuitable for the analysis of processes that occur during actual reading (Lorch, Balota, & Stamm, 1986; Seidenberg, Waters, Sanders, & Langer, 1984). Of particular concern for the present research is that the effect of word frequency may be exaggerated in the lexical decision task

due to the influence of post-lexical processes (Balota & Chumbley, 1984, 1985; Chumbley & Balota, 1984). In this view, it is possible that assessment of attention demands in Experiments 1 - 3 (also see Becker, 1976) reflected the demands associated with post-lexical processing rather than the demands of recognition. Therefore, it is important to investigate the demands of word recognition in a context other than the lexical decision task.

It has been suggested that word pronunciation tasks provide a more direct index of word recognition than do lexical decision tasks (Seidenberg et al., 1984). Pronunciation and lexical decision tasks presumably both involve the activation of lexical representations (Balota & Chumbley, 1985; Lorch, Balota, & Stamm, 1986; Seidenberg et al., 1984; however, see Coltheart, 1978; Coltheart, Davelaar, Jonasson, & Besner, 1977 for an alternative view). In the pronunciation task, however, a response can be made without the involvement of a decision stage that is ubiquitous to the lexical decision task. It should be noted, however, that the verification model does not explicitly include provision for phonological codes. Therefore, it is not clear exactly how the model accommodates performance on a pronunciation task. The most

likely possibility is that phonological codes are post-lexical in the verification model such that information regarding the pronunciation of a word would be made available after verification had been completed. In this view, and in accord with Becker (1976), attention demands associated with word recognition in the pronunciation task would be located in the verification process.

In the present research, a pronunciation task was used in place of the lexical decision task that was used in Experiments 1-3. The same dual-task change paradigm was implemented. The primary task, pronunciation, involved naming visually presented words. The secondary task involved discrimination between two auditory tones.

The pronunciation task and the auditory probe task were performed in single- and dual-task conditions. Single-task performances served as baselines from which to calculate performance changes in the corresponding dual-task conditions. On dual-task trials, subjects were required to decide whether the tone was a probe (higher pitched tone) or a distractor (lower pitched tone). When a probe was detected, the pronunciation response was to be forfeited and a probe response made. When a distractor was presented, a pronunciation response was to be made.

Auditory tones (i.e., probes and distractors) were presented at 167 ms SOA following presentation of words. Probe responses were divided into Detection and Movement measures. The predictions for the Detection measure are relatively straightforward. In accord with Becker (1976) and with the results of the previous experiments, demands of word recognition should be reflected in single- to dual-task decrements in probe Detection performance. Because resource demands of recognition presumably vary with word frequency (Becker, 1976), Detection decrements should be larger during low- than during high-frequency trials. Performance decrements will be reflected by longer probe latencies in the dual- than the single-task condition. A failure to obtain this pattern of results would raise questions about whether the findings reported in the previous experiments and by Becker (1976), reflected demands of word recognition or whether the results were due to demands associated with post-lexical processes in the lexical decision task.

In the change paradigm it is assumed that responses to the primary task are successfully inhibited when a response is to be made to a secondary task stimulus (Logan, 1985; Logan & Burkell, 1986; Logan & Cowan, 1984). In the present study the assumption was made that pronunciation responses

are inhibited and therefore will not interfere (e.g., in a Stroop-like manner) with responses to auditory probes. Accordingly, single- to dual-task decrements in probe Movement performance are not predicted.

Method

Subjects

Eight undergraduate students participated in partial fulfillment of a course requirement.

Apparatus and Stimuli

The apparatus was the same as that used in Experiment 2. Words for the practice trials were the same as those used in Experiment 1. There were a total of 240 words used in the experiment proper (i.e., 48 single- and 192 dual-task). These words were the same as those described in Experiment 1. Each subject saw a unique random order of the words in both the single- and dual-task conditions. Orders were generated with the restriction that half the words in each half of the set were high-frequency and the other half were low-frequency. In the dual-task condition, orders were further constrained in that (a) in each half of a set 25% of the trials were probe trials, (b) half of the probe trials in each half of the set occurred when a high-frequency word was presented, and (c) half of the critical items were

presented in each half of the set, half of these being high-frequency words.

Procedure

A session consisted of three blocks of trials: practice, single-task, and dual-task. The practice block consisted of 32 single-task pronunciation trials, followed by 32 single-task probe trials and then 32 dual-task trials. The single-task baseline condition consisted of 52 pronunciation trials followed by 52 probe trials. The first four trials in each condition served as practice. The dual-task condition consisted of 208 (16 practice + 192 experimental) dual-task trials.

In the single-task pronunciation condition, subjects fixated on a centrally presented dot and started trials by pushing and holding in the center key. After 500 ms, the fixation dot was replaced by a letter string and subjects pronounced the word as quickly as possible. The center key was held in throughout the trial. After 2000 ms had elapsed a "reset" message appeared and the subjects pressed the lower key to end the trial. The word disappeared from the screen when the VOR was activated or if the center key was released.

In the single-task auditory probe condition, the

fixation dot was replaced by a string of five asterisks. The asterisks were presented to simulate the procedure that would be used in the dual-task condition. When a distractor tone was presented, subjects continued holding in the center key until a "reset" message appeared and they were to press the lower key to end the trial. On "probe" trials, subjects released the center key as quickly as possible upon detection of a probe, and then quickly pushed the top key.

In the dual-task condition the fixation dot was replaced by a letter string. On "distractor" trials, subjects were to continue with the pronunciation component of the dual-task. On "probe" trials, subjects were to quickly respond to the probe by pressing the top key. That is, when a probe was detected, the pronunciation component of the dual-task was forfeited and priority given to making a probe response.

In the single-task auditory probe and dual-task conditions, the SOA between presentation of the visual stimulus and the tone stimulus was 167 ms. Probe tones (625 hz) were presented on 25% of the trials; distractor tones (333 hz) were presented on the other 75% of the trials. Pronunciation latency was measured from presentation of a letter string until activation of the VOR. Probe Detection

latency was measured as time between presentation of a tone and the release of the key. Probe Movement latency was the time taken to move the index finger up to push the top key.

Results and Discussion

Latencies greater than 2.5 standard deviations from the mean of the respective conditions were defined as outliers, removed from the data set, and the means were recomputed. Across subjects, 2.4% of the probe latencies and 4.9% of the pronunciation latencies were defined as outliers. In addition, 2.7% of the pronunciation trials were lost due to failure of the VOR to detect a response. In the following analyses, Condition (single- versus dual-task) and Frequency (high- versus low-frequency) are both repeated measures.

Errors on the auditory probe task were infrequent. On the average, errors were made on 5.4% of the probe trials and 2.6% of the distractor trials. In the dual-task condition, errors on the pronunciation and probe tasks were reciprocal: When probe tones were missed, a word response was made; when a pronunciation was missed, a probe response occurred. Analyses of the error data did not show any significant effects.

Auditory probe responses

The Detection and Movement latency data are shown in

Table 5. The Detection and Movement data were converted into decrement scores as described in Experiment 1. A one-way analysis of the Detection decrement data showed that performance decremented from single- to dual-task conditions more during low-frequency than during high-frequency trials (decrements of 98 vs. 74 ms), $F(1, 7) = 11.67$, $p < .01$. This finding is consistent with the Detection results reported in Experiments 1 - 3 and indicates that fewer resources were available for the probe task during recognition of low-frequency as compared to high-frequency words in the dual-task condition.

A one-way analysis of the Movement decrement scores did not show any significant effects, suggesting that response competition did not exist between pronunciation responses and probe responses.

Pronunciation responses

Pronunciation latencies are summarized in Table 6. A one-way analysis of the single-task pronunciation latencies

showed that responses were faster to high- than to low-frequency words (575 vs. 616 ms), $F(1, 7) = 44.52$, $p < .001$. This result reflects the word frequency effect often reported in the literature (Chumbley & Balota, 1984; Scarborough, Gerard, & Cortese, 1979; Waters & Seidenberg, 1985).

A 2 (Condition) x 2 (Frequency) analysis of the pronunciation responses also showed a word frequency effect where latencies were longer to low- than to high-frequency words (672 vs. 632 ms), $F(1, 7) = 21.44$, $p < .002$. Latencies were also longer in the dual-task than the single-task condition (708 vs. 596 ms), $F(1, 7) = 59.81$, $p < .001$. However, because the interaction of word frequency and Condition was not significant, $F(1, 7) < 1$, it is not possible to determine whether performance decrements occurred because fewer resources were allocated towards the pronunciation task in the dual- than in the single-task condition, or whether performance decrements reflect some

form of concurrence cost.

To summarize, the results of the present experiment are compatible with those reported in the previous experiments in that single- to dual-task decrements in Detection performance were greater during concurrent processing of low-frequency than high-frequency words. These findings are consistent with the notion that attention is required to verify words and that more attention demanding verification cycles are required to recognize low-frequency as compared to high-frequency words (Becker, 1976). In contrast to the assessment of attention demands in the context of lexical decisions, the present results cannot be attributed to the demands of post-lexical decision processes.

In Experiments 1 and 3, decrements in lexical decision performance were found, indicating that fewer resources were allocated to the lexical decision task in the dual-task than the single-task condition. In addition, it was found that lexical decision performance decremented more during low-than during high-frequency trials, suggesting that processes which are sensitive to word frequency in lexical decisions are controlled. This conclusion was supported by the results of Experiment 3 which showed that Detection and lexical decision performance were affected by variations in

the resource demands of the probe task but only during low-frequency trials. However, because post-lexical decision processes in the lexical decision task may be frequency sensitive (Balota & Chumbley, 1984; Balota & Chumbley, 1985; Chumbley & Balota, 1984), it is not clear whether lexical, post-lexical, or both of these operations are controlled processes.

In Experiment 4, single- to dual-task performance decrements on the pronunciation task were also observed. However, in contrast to the lexical decision results reported in Experiments 1 and 3, decrements in pronunciation performance did not vary with word frequency. Because post-lexical decision processes presumably are not included in the pronunciation task, these results indicate that lexical access is not differentially affected by resource allocation strategies. In this view, and in accord with Becker (1976), it is suggested that although attention is required to verify words, verification cannot be defined as a controlled process.

To summarize, the results of the present experiment and those of the previous experiments are consistent with the notion that word frequency determines, to some extent, the attention demands of recognition as well as post-lexical

processing. Because only lexical decision performance was found to be differentially affected by resource allocation strategies, it is possible that only post-lexical processing is controlled. This conclusion is tentative, however, because the influence of resource allocation strategy on lexical access has not directly examined.

EXPERIMENT 5

In Experiment 4, the attention demands of word recognition were assessed by combining a pronunciation task with an auditory probe task. It was found that Detection performance decremented from single- to dual-task conditions. Moreover, decrements were greater during low-than during high-frequency trials. These results show that attentional resources are required to recognize words and that more resources are required to recognize low-frequency as compared to high-frequency words. The allocation of resources to the probe task in the dual-task condition also resulted in decrements in pronunciation performance. However, decrements in pronunciation performance did not vary with word frequency. Therefore, although word recognition requires attentional resources, recognition is not affected by resource allocation strategies. In this view, recognition cannot be characterized within the automatic/controlled framework.

In contrast to the lexical decision task, the pronunciation task does not include post-lexical decision processes that are frequency sensitive (Seidenberg et al., 1984). Therefore, the demands of recognition in the pronunciation task are attributable to processes associated

with lexical access. In this view, and in accord with Becker (1976), the results of Experiment 4 are consistent with the notion that (a) verification is an attention demanding process, (b) that more attention demanding verification cycles are required to recognize low-frequency as compared to high-frequency words, and (c) verification cannot be defined as a controlled process.

It has been suggested that in addition to automatic and controlled processes there also exist mandatory (Herdman & Friedman, 1985; Navon & Gopher, 1979) or obligatory (Odgen, Martin & Paap, 1982; Paap and Odgen, 1983) processes. Mandatory processes are similar to automatic processes in that they occur without intention, but differ in that they require resources. Unlike resource demands associated with controlled processing, however, mandatory processes occur beyond the control of resource allocation policies and thus are not affected by the resource demands of other concurrently performed tasks.

The characterization of verification as a mandatory process complies with the results of Experiments 1 - 4. Accordingly, single- to dual-task decrements in Detection performance occurred because the mandatory resource demands of verification limited the amount of resources available

for the probe task. Decrements in Detection performance interacted with word frequency because resources are mandatorily required longer during low- than high-frequency words. Decrements in pronunciation performance did not vary with word frequency because the mandatory operations in the verification process are not affected by the allocation of resources towards the probe task. That is, verification demands resources regardless of allocation strategy.

The purpose of the final experiment was to directly assess the notion that verification is a mandatory and not a controlled process. This was achieved by combining the pronunciation and auditory probe tasks and manipulating the resource demands of the probe task. In Experiment 3 the difficulty of the probe task was manipulated by varying task complexity from a simple to a choice condition. In the present experiment only a choice probe task was used. The difficulty of this task was manipulated by varying the discrimability between distractor and probe tasks. In the easy condition, the probe and distractor tones were distant in pitch. In the hard condition, probe and distractor tones were close in pitch.

Probes were presented at 167 ms (SOA) after the presentation of letter strings. Based on the results of the

previous experiments, it was assumed that when probed at this SOA verification of high-frequency words is generally complete but verification of low-frequency words is still ongoing and demanding of attention. Therefore, overlap in demand for resources between the pronunciation and the probe task was presumed to occur primarily during low-frequency trials. If verification is a controlled process, then decrements in pronunciation and probe task performance should be accompanied by performance shifts across probe-difficulty. These decrements and performance shifts should be greater during the more resource-dependent low-frequency trials. If verification is a mandatory process, then single- to dual-task decrements in Detection performance should also be found. Moreover, because the mandatory resource demands of verification are assumed to vary with word frequency, decrements in Detection performance should be greater during low- than during high-frequency trials. However, because mandatory processes occur beyond the control of allocation policy, the allocation of resources to the probe task should not result in decrements in pronunciation performance that are differentiated across word frequency or vary with changes in probe-difficulty.

As in the previous experiments, auditory probes were divided into Detection and Movement measures which indexed the demands of cognitive (e.g., encoding, memory access, and decision processes) and response output operations, respectively. The manipulation of task-difficulty was assumed to increase the resource demands of decision processes in the probe task. Therefore, shifts in probe performance were expected to be reflected in the Detection but not Movement latency.

Method

Subjects

Twenty undergraduate students participated in this experiment to partially fulfill a course requirement.

Apparatus and Stimuli

The apparatus and word stimuli were the same as described in Experiment 4. In the easy condition, probe tones were 625 hz and distractor tones 313 hz. In the hard condition, probe tones were 333 hz and distractors 313 hz. Each subject received a unique random order that was constructed with the same restrictions described in Experiment 4.

Design and Procedure

Subjects participated in one session that was divided

into easy and hard blocks. Each block consisted of practice, single-task, and dual-task trials. In the practice conditions, subjects performed 16 trials of pronunciation, auditory probe, and dual-task practice. The single-task conditions consisted of 26 (2 practice + 24 experimental) pronunciation trials and 26 (2 practice + 24 experimental) auditory probe trials. The dual-task conditions consisted of 104 (8 practice + 96 experimental) trials of combined pronunciation and probe task. Single-and dual-task trials proceeded as described in Experiment 4. All subjects received the easy condition first and the hard condition second.

Results and Discussion

Outliers were defined as in the previous experiments and removed from the data set. On the average, 1.9% of the probe scores and 4.9% of the pronunciation scores were defined as outliers. In the following analyses, Difficulty (easy vs. hard), Condition (single- vs. dual-task) and Frequency (high- vs. low-frequency) are all within subjects factors.

Auditory probe responses

Latencies. The single- and dual-task Detection and Movement latencies are shown in Table 7. A one-way analysis

showed that single-task Detection latencies were longer in the hard- than the easy-probe condition (446 vs. 378 ms), $F(1, 19) = 17.05$, $p < .001$. This indicates that the Difficulty manipulation had the desired effect of increasing the demands of processes indexed by the Detection measure.

The Detection and Movement data were converted to decrement scores as described in Experiment 1. A 2 (Difficulty) X 2 (Frequency) analysis of the Detection decrement data showed that the main effect of Frequency approached reliability, $F(1, 19) = 4.28$, $p = .053$, indicating that single- to dual-task decrements in Detection performance were greater during low-frequency than during high-frequency trials (decrements of 81 vs. 65 ms). This finding is consistent with the assumption that more attentional resources are required to recognize low- than high-frequency words. The interaction of Difficulty X Frequency was not reliable ($F < 1$), indicating that the manipulation of probe difficulty did not result in

differential decrements in Detection performance during low-as compared to high-frequency trials. This suggests that the attentional resources required by frequency sensitive processes in the pronunciation task, are not the same resources that are required by the processes sensitive to task difficulty in the probe task.

A one-way analysis of the single-task Movement latencies was not reliable, $F(1, 19) = 1.34$, $p = .26$. Therefore, the manipulation of probe-task difficulty did not change the demands associated with outputing probe responses. A 2 (Difficulty) X 2 (Frequency) analysis of the Movement decrement scores did not show any significant effects.

Errors. Sensitivities to auditory probes were analyzed by converting responses to d' scores. A 2 (Difficulty) X 2 (Frequency) analysis of the d' scores showed a significant interaction of Difficulty X Frequency, indicating that single- to dual-task decrements in probe sensitivity were greater during low-frequency than during high-frequency trials (decrements of .38 and .07), $F(1, 19) = 6.77$, $p < .018$. This suggests that the resource demands of recognizing words in the pronunciation task limited the availability of resources for the hard-probe task, but only during low-frequency trials.

In summary, the latency data show that Detection performance decremented from single- to dual-task conditions more during low- than high-frequency trials. These results replicate those reported in the previous experiments. However, in contrast to the results of Experiment 3, changes in probe task difficulty did not result in shifts in the magnitude of single- to dual-task decrements in Detection performance. Therefore, the latency data are not consistent with the notion that word recognition in the pronunciation task is a controlled process.

Pronunciation responses

Latencies. The single- and dual-task pronunciation latencies are shown in Table 8. A 2 (Frequency) X 2 (Difficulty) analysis of the single-task data showed that pronunciation latencies were longer to low- than to high-frequency words (637 vs. 591 ms), $F(1, 19) = 23.72$, $p < .001$. This replicates the word frequency effect reported in Experiment 4. The main effect of Difficulty was also reliable, $F(1, 19) = 5.06$, $p < .037$, indicating that pronunciation latencies were faster in the hard than in the easy single-task condition (602 vs. 626 ms). This finding most likely reflects a practice effect due to the fact that subjects received the hard condition after the easy

condition.

A 2 (Condition) X 2 (Frequency) X 2 (Difficulty) analysis showed that pronunciation latencies were longer in the dual- than in the single-task condition (792 vs. 614 ms), $F(1, 19) = 80.45$, $p < .001$. This finding is consistent with the assumption that fewer resources were available for the pronunciation task in the dual- than in the single-task condition. The main effect of Frequency also approached significance, $F(1, 19) = 3.73$, $p < .068$. The means show that pronunciation latencies were longer to low- than to high-frequency words (717 vs. 688 ms). More importantly, however, Frequency did not interact with Condition, $F(1, 19) = 1.56$, $p = .23$, indicating that single- to dual-task decrements in pronunciation performance did not differ between high- and low-frequency trials. Furthermore, the manipulation of probe-difficulty did not result in differential decrements during high- versus low-frequency trials ($F < 1$). Therefore, changes in the resource demands

of the probe task did not affect pronunciation performance.

Errors. Pronunciation errors did not occur in the single-task condition. In the dual-task condition pronunciation errors were reciprocal with errors on the probe task. When a probe response was missed a word pronunciation was made. A 2 (Difficulty) X 2 (Frequency) analysis showed a main effect of Difficulty where more errors were made in the hard-probe than in the easy-probe condition (3.8% vs. 2.6%), $F(1, 19) = 11.99$, $p < .003$. A second type of error occurred during distractor trials when a probe response was incorrectly made and a pronunciation response was missed. This type of error was made on 3.7% of the trials. A 2 (Difficulty) X 2 (Frequency) analysis did not show any significant effects.

To summarize, the Detection results show that (a) word recognition in the pronunciation task demands attentional resources and (b) more resources are required during recognition of low- as compared to high-frequency words. These results are consistent with the notion that when probed at 167 ms SOA, verification of high-frequency words is generally complete, but verification of low-frequency words is still ongoing and demanding of attention. Because the manipulation of probe-difficulty did not result in

shifts in either pronunciation or in Detection performance, it cannot be concluded that verification is a controlled process. Instead, the evidence supports the notion that the resource demands of word recognition are independent of allocation policy. In this view, it is suggested that verification is a mandatory process.

The conclusion that verification is a mandatory process is dictated by the failure to reject the null hypothesis that shifts in resource demands do not affect word recognition. This conclusion, however, is qualified, to a certain extent, by the Detection error data which show that sensitivity to probes only decremented significantly during low-frequency trials and only in the hard probe condition. This results suggests that performance shifted with an increase in probe difficulty, but only during low-frequency trials. However, it must be noted that throughout the present research Detection latency has been identified as the primary measure of Detection performance. Therefore, the view taken here is that the error data are not sufficient to warrant rejecting the null hypothesis that performance on the probe task did not shift with changes in probe task difficulty.

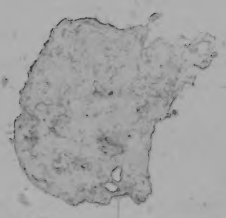
Shifts in performance may not have been observed because

resource demands did not differ significantly between easy-probe and hard-probe conditions. That is, the task difficulty manipulation used in this study may not have been strong enough to result in substantial changes in resource demands. However, the sizeable effect of probe difficulty on single-task Detection performance illustrates that task difficulty had the desired affect of increasing the demands of the probe task. Moreover, it should be noted that a similar task difficulty manipulation was found to be sufficient to produce an interaction of Difficulty X Frequency in Experiment 3.

A second possible reason that task difficulty did not result in performance shifts is that resources may not have been limited in the dual-task condition. That is, the total available capacity may not have been exceeded by the combined resource demands of the pronunciation task and the probe task. Contrary to this argument, however, is the finding that Detection and pronunciation performances decremented from single-task to dual-task conditions. Moreover, as in the previous experiments single- to dual-task decrements in Detection performance were greater during low-frequency than high-frequency trials, thus illustrating the interactive effects of resource demands and

frequency sensitive processes in the pronunciation task.

To summarize, although single- to dual-task decrements were observed in both Detection and pronunciation performance, as indexed by the latency measures, these decrements were not found to shift with changes in task difficulty. These results contrast those reported in Experiment 3 in which lexical decision and Detection performance were found to shift with task difficulty. The probe error data, on the other hand, appear to show a shift in accuracy with task difficulty. However, because latency was the primary measure of probe task performance, the error data are not considered sufficient to justify rejection of the null hypothesis that difficulty did not effect probe performance. The error data do necessitate caution, however, when interpreting the latency data. In this view, it is tentatively concluded that while post-lexical processes in the lexical decision task are controlled, verification is best defined as a mandatory process.



General Discussion

A dual-task change paradigm was used to assess the attention demands of visual word recognition. In the change paradigm, the demands of a primary task are indexed by secondary task performance: The greater the demands of processing the primary task, the lower the corresponding performance on the secondary task (Logan & Burkell, 1986). The secondary task used in the present research was an auditory probe task. Responses to probes were divided into Detection and Movement components, which were assumed to reflect the resource demands associated with central-cognitive and response output operations, respectively.

The first three experiments examined the attentional demands of visual word recognition within the context of a lexical decision task. In Experiment 1, the demands of recognition were assessed early versus late in the processing sequence by presenting probes either at 0 ms or 167 ms (SOA) following presentation of letter strings. Detection performance was found to decrement from single- to dual-task conditions, indicating that attentional resources are required to recognize words in the lexical decision task. In addition, decrements in Detection performance were

larger during low- than during high-frequency trials, indicating that the attention demands of recognition vary with word frequency. The pattern of performance decrements across SOA conditions was such that attentional resources are required for a longer period of time to recognize low-as compared to high-frequency words.

Performance on the lexical decision task was also found to decrement from single- to dual-task conditions. During high-frequency trials these decrements did not vary across SOA. During low-frequency trials, however, decrements were larger in the long than the short SOA condition. When considered alone, single- to dual-task decrements are not especially informative because performance changes may occur because of concurrence cost (Navon & Gopher, 1979). However, the interactive effects of word frequency and SOA on decrements suggests that performance varied as a function of resource demands. In particular, the results suggest that in the dual-task condition resources were allocated away from lexical decisions until it was decided that a probe was not to be presented. Accordingly, resources were presumably not available for lexical decisions for a longer period of time in the long than in the short SOA condition. In this view, decrements in lexical decision performance did not

vary with SOA during high-frequency trials because the attention demands of recognition were completed shortly after presentation of these words. On the other hand, larger decrements were found in the long than in the short SOA condition during low-frequency trials, because recognition of these words requires resources for a longer period of time.

The lexical decision and probe Detection results obtained in Experiment 1 suggest that the attention demands of word recognition vary with word frequency. The Detection findings, however, were compromised by a potential confound inherent in the procedure. More specifically, because the response requirements of the lexical decision and probe tasks overlapped to some extent, a response facilitation hypothesis could (at least partially) account for the Detection results. This confound was addressed and corrected in Experiment 2 by separating the response requirements of the lexical decision and probe tasks.

The results of the second experiment were consistent with those reported in Experiment 1. Detection performance decremented from single- to dual-task conditions and these decrements were greater during low- than during high-frequency trials. Therefore, it was concluded that

attentional resources are required to recognize words and that resource demands vary with word frequency.

When considered within the automatic/controlled framework (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), the results of Experiments 1 and 2 suggest that recognition is a controlled process insofar as attentional resources are required to determine the lexicality of visually presented words. Experiment 3 extended the characterization of recognition as a controlled process by examining the affect of resource allocation strategy on word processing. One criterion for deciding that a process is a controlled process is that it will be affected by changes in the resource demands of concurrently activated processes. The hypothesis that lexical access is affected in this manner was tested by manipulating the resource demands of the auditory probe task.

Probes were presented at 167 ms SOA. Based on the results of the previous experiments, it was assumed that when probed at this SOA, recognition of low-frequency words was still ongoing and demanding of attentional resources. Recognition of high-frequency words, on the other hand, was assumed to be complete. The results of Experiment 3 showed that changes in probe-difficulty resulted in shifts in

Detection and lexical decision performance, but only during low-frequency trials. This finding demonstrates that frequency sensitive processes in word recognition are affected by resource allocation factors, and in this sense word recognition can be defined as controlled processes.

In summary, the first three experiments provide important insights into the dynamic nature of processes involved in visual word recognition. The results of these experiments suggest that (a) recognition is an attention demanding process, (b) attention demands of recognition vary with word frequency, and (c) recognition in the lexical decision task can be construed as a controlled process.

The investigations of attention demands in Experiments 1 - 3 were conducted within the context of the lexical decision task. In light of recent controversy regarding the use of the lexical decision task to investigate word recognition (Lorch et al, 1986; Seidenberg, 1984), and in particular the possibility that frequency effects in lexical decisions may reside in post-lexical processes (Balota & Chumbley, 1984, 1985; Chumbley & Balota, 1984), the assessment of attention demands in word recognition needed to be extended to other task domains. To this end, the attention demands of recognition were assessed in Experiment

4 by replacing the lexical decision task used previously, with a pronunciation task. Pronunciation tasks are assumed to provide a purer index of lexical access than the lexical decision task and presumably word frequency effects in pronunciation are less attributable to post-lexical processing (Seidenberg et al, 1984; however, see also Balota & Chumbley, 1985)

The Detection results obtained in Experiment 4 were consistent with those reported in the previous experiments: Detection performance decremented from single- to dual-task conditions and these decrements were greater during low-than during high-frequency trials. Therefore, it was concluded that (a) lexical access requires attentional resources and (b) the extent to which resources are required to access lexical representations varies with word frequency.

A word frequency effect was also obtained in Experiment 4 where pronunciation latencies were faster to high- than to low-frequency words. Moreover, pronunciation performance was found to decrement, indicating that less capacity was allocated to the pronunciation task in the dual- than in the single-task condition. However, decrements in pronunciation performance did not vary with word frequency, suggesting that processes underlying the word frequency effect in word

pronunciation are not controlled insofar as they are not affected by resource allocation policy.

Experiment 5 provided a further examination of resource allocation factors on lexical access. This was done by implementing the probe-difficulty manipulation used in Experiment 3. The Experiment 5 latency data showed that neither Detection nor pronunciation performance shifted as a function of probe-difficulty. Therefore, although attentional resources are required to access lexical representations, these resource requirements occur beyond the control of a resource allocation policy. These findings suggest that lexical access is best characterized as a mandatory process. It should be noted, that the Detection latency data were qualified by the error data which suggested the presence of performance trades during low-frequency but not high-frequency trials. However, because the primary analysis used throughout the present research focused on latencies, the error data were not considered as sufficient evidence to warrant the conclusion that probe task performance shifted with changes in task difficulty. Nevertheless, it is clear that the conclusion that resource requirements of word recognition in the pronunciation task occur beyond control of allocation policy

must be accepted with caution.

To summarize, the present research demonstrates that recognition of words requires attentional resources and that more resources are required to recognize low- than high-frequency words. It is suggested that lexical access is a mandatory process in that it demands attentional capacity but is not affected by resource allocation factors. Post-lexical processes, such as the decision processes inherent in the lexical decision task, are influenced by resource allocation factors are thus are characterized as controlled processes.

Attention Demands in the Verification Model

The present research was conducted within the framework of Becker's (1976, 1979, 1980, 1982, 1985; Becker & Killion, 1977; Eisenberg & Becker, 1982) verification model. According to Becker, word recognition consists of sensory feature extraction and verification. The attention demands of word recognition are assumed to arise during verification such that each verification cycle requires a set amount of resources. The order in which words are submitted for verification is presumably dictated by word frequency such that recognition of low-frequency words requires more verification cycles. Accordingly, it is assumed that

attentional resources are required for a longer period of time to identify low- as compared to high-frequency words.

The results of the present research are consistent with Becker's description of attention demands in visual word recognition. When examined within the context of lexical decisions as well as word pronunciation, the attention demands of recognition were found to be greater for low-frequency than for high-frequency words. In addition, when attention demands were assessed early versus later in the recognition process (Experiment 1), resources were found to be required for a longer period of time to recognize low-as compared to high-frequency words.

Although the locus of attention demands in word recognition have been identified by Becker (1976), the nature of these demands has not been explicitly characterized. To this end, the present research adds to Becker's account by providing a characterization of verification as a mandatory process. In this view, verification is initiated without intention, requires attentional resources, and is not affected by the resource demands of other concurrently performed tasks.

The conceptualization of verification as a mandatory process is a relatively restrictive description of the

attention demands of word recognition. Although this description is consistent with the results of the present research, a mandatory processing assumption must also be able to account for findings in other research paradigms. In this view, it should be noted that a mandatory processing characterization is consistent with research showing that word identity is processed unintentionally in the Stroop task (Dyer, 1973). On the other hand, mandatory processing cannot be used to account for the finding that the magnitude of Stroop effects are affected by the attention demands of other concurrent processes (Kahneman & Chajczyk, 1983). One possible explanation is that attention demands in the Stroop task are not restricted to lexical access but also include demands associated with post-lexical processes. For example, attention may be required to select between the response codes corresponding to word identities and colour names (Humphreys, 1985). That is, although activation of word identity in the Stroop task may demand resources, additional resources may be required to complete post-lexical decision processes. In accord with the present research, demands of lexical access may be mandatory and demands associated with post-lexical processing may be controlled. The notion that some portion of the resource

demands in the Stroop task are mandatory is supported by the finding that while Stroop effects can be diluted, they still persist (Kahneman & Chajczyk, 1983; also see Kahneman & Henik, 1981).

The concept of mandatory processing has been used to describe attention demands in task domains other than word recognition (Navon & Gopher, 1979; Herdman & Friedman, 1985). Most germane to the present research is the suggestion that letter encoding is a mandatory process (Paap & Odgen, 1981). Paap and Odgen (1981) had subjects perform a letter categorization task (i.e., vowel/consonant) in combination with a simple auditory probe task. Letters were preceded either by a predictive prime, a nonpredictive prime, or no-prime. Auditory probes were presented following presentation of the primes in an effort to determine whether encoding of the primes demanded attentional resources.

In the predictive condition letter categorization was facilitated when the prime was related to the target (i.e., same category), and inhibited when the prime was unrelated to the target. This suggests that subjects were intentionally using the prime in the predictive condition. In the nonpredictive condition, facilitation was found

during related trials but inhibition was not obtained during unrelated trials. This indicates that subjects were not intentionally processing the primes in the nonpredictive condition (Posner & Snyder, 1975). Analysis of the probe data showed that responses to probes were longer during the prime as compared to the no-prime condition, indicating that letter encoding (in this case encoding of primes) demands resources. Moreover, it was found that probe responses were longer even in the nonpredictive priming condition, that is, when subjects were presumably not intentionally processing the primes. Therefore, the Paap and Odgen (1981) findings suggest that letter encoding is a mandatory process in that it proceeds without intention and demands attentional resources.

The Paap and Odgen (1981) findings are important to investigations of attention in word recognition because they show that demands may occur during relatively low-level encoding operations. In Becker's model encoding is described as the extraction of features for the purpose of forming a candidate set of word units. That is, letter encoding, per se, is neither considered to be a requisite nor a resource demanding process in word recognition. This approach is supported by research suggesting that during

word processing encoding may be more or less unitized at the word level (Carr & Pollatsek, 1985; LaBerge & Samuels, 1974; Massaro, 1979). In this view, it may be that letter encoding does not contribute significantly to the resource demands of word recognition.

Extension of the Verification Model

The inclusion of letter encoding in word recognition has been proposed by Paap et al. (1982). In the Paap et al. activation-verification model, the integrity of the verification process as described by Becker is maintained. However, in contrast to Becker's account of encoding, Paap et al. provide a detailed description in which encoding is divided into two phases. In the first phase, feature extraction serves to activate letter units stored in a memory system called the alphabetum. In turn, the activation of constituent letters in the alphabetum activates word units in the lexicon. As in Becker's model, word frequency is presumed to determine the order in which candidates are submitted for verification. Word frequency does not affect the activation of letter units in the alphabetum, nor word units in the lexicon.

The notion that letter encoding requires resources (Paap & Odgen, 1981; see also Johnson, Forester, Calderwood, &

Weisgerber, 1983) can be addressed with the activation-verification model. Accordingly, the mandatory processing demands of letter encoding would be attributed to the activation of units in the alphabetum. In this view, it follows that encoding in the lexicon is also a mandatory process. Therefore, insofar as letter and lexical encoding are requisite processes in word recognition (Paap et al., 1982), the attention demands of word recognition would be attributed to (a) the mandatory encoding of letter units in the alphabetum (Paap & Odgen, 1981), (b) the mandatory encoding of units in the lexicon, and (c) the mandatory demands associated with the sampling and comparison processes in verification (Becker, 1976).

Paap et al. (1982) assume that lexical decisions are usually based on the verification process. However, in cases for which verification is not possible, the activation levels of word units in the lexicon may be used to make a lexical decision. Activation in the lexicon is presumed to be insensitive to word frequency. Therefore, decisions based on activation levels are not predicted to show frequency effects. In this view, although lexical decisions that are made based on activation levels may mandatorily demand resources, these demands should not vary with word

frequency.

Paap et al. (1982) suggested that one way to eliminate a verification stage is to use a backward masking paradigm. Verification presumably involves the comparison of a constructed representation to a representation in sensory memory. Backward masking is assumed to eliminate verification by interfering with the availability of the sensory representation. Therefore, a possible test for pre-verification attention demands would be to incorporate a masking procedure with the dual-task, change, paradigm used in the present research. On the assumption that letter and lexical encoding are mandatory processes in word recognition, attention demands of word processing should be observed. However, because pre-verification processes are presumably not frequency sensitive, attention demands in a masking paradigm should not be greater for low- than for high-frequency words.

It should be noted, however, that word frequency effects have recently been found in research that employed a backward masking paradigm (Dobbs, Friedman, & Lloyd, 1985). This finding contradicts the prediction that masking should eliminate word frequency effects (Paap et al., 1982) and suggests that pre-verification processes are frequency

sensitive. Dobbs et al. (1985) suggest that frequency effects can be isolated to activation of units in the lexicon. This suggestion is based on research showing that word frequency and stimulus intensity are additive, and thereby presumably involve different processes (Becker & Killion, 1977; see also Besner & Swan, 1982). In accord with the activation-verification model, stimulus intensity may affect letter activation and word frequency may affect lexical activation.

The investigation of attention demands in word recognition may provide further evidence regarding the locus of frequency and stimulus intensity effects in word recognition. For example, insofar as pre-verification processes are frequency sensitive (Dobbs et al., 1985), differential demands associated with recognition of high-versus low-frequency words should be found in a backward masking paradigm. Further investigations could refine the analysis to examine the interactive effects of stimulus intensity and-frequency factors on attention demands. The importance of this research would be to provide converging evidence concerning the differentiation of letter and lexical encoding in word recognition.

In summary, Paap et al. (1982) incorporate the

verification process described by Becker into their activation-verification model, but place a greater emphasis on processes involved in letter and lexical encoding. In this manner, the Paap et al. model provides a framework to extend the investigation of attention demands in word recognition. Insofar as letter and possibly lexical encoding are requisite and mandatory processes in word processing (Paap et al., 1982), attention demands should be observed even when verification has been eliminated. It is possible, however, that letter and lexical encoding do not require significant amounts of attention relative to the overall demands of visual word recognition. In this view, the isolation of attention demands to the verification process, as outlined by Becker, may be sufficiently descriptive. Indeed, the rewards of investigating letter and lexical encoding demands in word recognition may prove to be minimal.

Contextual Priming and Attention Demands of Word Recognition

The verification model has been successfully used to address a variety of research findings in the word recognition literature (see Besner & Swan, 1982 for a review). One area of research in which the verification model has proven to be particularly suited is that concerned

of contextual priming (Carr & Pollatsek, 1985). In the verification model, it is assumed that contextual priming results in the formation of a semantically defined set of candidates. These candidates are submitted for verification before a sensory-defined set of candidates can be formed. A target word that is related to the prime stimulus would be a member of the semantically defined set. Thus, sampling of a related word would occur early in the verification process relative to a word presented out of context. Accordingly, a target word that is related to a prime would require relatively fewer verification cycles, thereby resulting in faster word recognition. On the other hand, a target word that is unrelated to the prime stimulus would not be represented in the semantic set. Verification of an unrelated word, therefore, involves exhaustive sampling of the semantic set followed by verification of items selected from the sensory defined set. Because more verification cycles are required, recognition is slower to unrelated words as compared to related word and words that are presented out of context.

The effects of contextual priming on the attentional demands of word recognition have been examined by Larochelle, Rodriguez, and McClelland (1980). These

researchers had subjects identify target words that were preceded either by an related sentence or by an unrelated sentence. The target words were flanked on either side by digits. Three response conditions were included. In the digit-alone condition responses were made only to digits. In the digit-first condition, responses were made first to digits and then to target words. In the digit-second condition, responses to digits were made after responses to target words had been elicited. It was assumed that if context allows word identification to proceed with fewer resource demands, then more resources should be available to perform the digit task in the related than in the unrelated condition.

The results showed that performance on the digit task was superior in the related as compared to the unrelated context condition, but only in the digit-second condition. This finding is consistent with Becker's (1976) notion that fewer verification cycles, and thus fewer attentional resources are required to recognize words in related than in unrelated conditions. The Larochelle et al. (1980) research, however, is not conclusive for two reasons. First, single-task measures were not obtained on either word identification or digit performance. Therefore, it is not

possible to determine whether performance on these tasks decremented, incremented, or did not change from single- to dual-task conditions. If, in fact, combined performance on these tasks either incremented or did not change from single-task levels, then a capacity interpretation of the results would not be equivocal (Norman & Bobrow, 1975; Navon & Gopher, 1979, Gopher & Navon, 1980). Secondly, responses to words in the unrelated context were found to be longer than responses to words in the related context. Therefore, in the digit-second condition, the time elapsed between digit presentation and allocation of attention towards the digits depended on whether a related or an unrelated context was presented. Accordingly, performance on the digit task may have varied due to differential loss of the digit memory trace during the variable time delay, and not because of differential capacity demands. A differential loss hypothesis seems especially plausible because context did not affect performance in either the digit-first or the digit-alone condition.

An additional limitation of the Larochelle et al. (1980) research is that it only provides a superficial examination of the effects of context on attention demands in word recognition. This limitation, however, was dictated by the

choice of Morton's (1969, 1970, 1979, 1982; Morton & Patterson, 1980) logogen model of word recognition as a conceptual framework. The logogen model represents a "passive" account of word recognition insofar as attention demands are not considered as part of the logogen system (Morton, 1969). Therefore, predictions concerning the attention demands of word recognition that are based on the logogen model are necessarily speculative and restricted.

In contrast to the logogen model, the verification model can be used to generate several very specific predictions beyond the basic prediction that fewer resources are required to recognize words in a related context as opposed to an unrelated context. For example, in the verification model it is assumed that contextually defined candidates are available for, and directed to, verification before a sensory defined set has been established. Therefore, verification of words should be initiated sooner in a contextually primed condition as compared to a nonpriming (neutral) condition. In this view, the attention demands associated with word verification should be observed sooner in a priming than in a nonpriming condition.

A second prediction that can be generated from the verification model is that the attention demands associated

with recognition should last longer in neutral and unrelated context conditions than in a related condition. This is because fewer verification cycles are presumably required to recognize contextually related words.

A third prediction can be made based on the assumption that recognition of words in an unrelated context involves verification of a contextually defined set followed by verification of a sensory defined set. In accord with this assumption, verification of words that are presented in an unrelated context presumably not only start sooner (i.e., because of the formation of a semantic set) than verification of words presented in a nonpriming condition, but should also last longer. Accordingly, the verification model predicts that the attention demands of word recognition in an unrelated context should be observed sooner and be found to persist longer as compared to demands associated with recognition of words in a nonpriming condition.

The various predictions described above could be tested by incorporating a contextual priming procedure with the dual-task, change, paradigm used in the present research. By presenting probes at different points during processing of target words (i.e., by varying SOA), the effects of

contextual priming on the attention demands in word recognition could be isolated. In addition to providing a further examination of attention demands in word recognition, this research would also provide a converging measure of the effects of contextual priming.

Attention in Direct Access Models of Word Recognition

The present discussion of attention demands in word recognition has centered primarily around the verification model. One reason for this approach is that with the exception of Becker (1976), word recognition theorists have not included attentional processes in their models. As discussed earlier, however, attentional factors can be assimilated into the Paap et al. (1982) activation-verification model by applying the assumptions made explicit by Becker (1976). For example, the assumption that each verification cycle requires attention can be incorporated without compromise into the activation-verification model. Additional assumptions regarding the attention demands of processes that precede verification may extend the accountability of the model to other task domains.

In comparison to verification-type models, the inclusion of attentional processes in other models of word recognition

may be difficult to achieve, and in fact, may challenge the conceptual foundations upon which the models are based. One such class of models are those based on the concept of direct access, the most well-known of which is Morton's logogen model (Morton, 1969, 1970, 1979, 1982; Morton & Patterson, 1980; also see Glushko, 1979; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982).

The logogen model is a direct access model because perceptual information is sent directly to a set of feature detectors called logogens. Each logogen is sensitive to specific evidence such that if a stimulus contains a feature of a particular word, then the feature count of the corresponding logogen is incremented. When enough information has been accumulated such that the threshold for that logogen is exceeded, then a code or a set of codes containing information about the word is made available. The word frequency effect is accounted for in the logogen model with the assumption that the amount of evidence that is necessary for activation of a logogen to exceed threshold varies with word frequency. That is, less activation (and thus less time) is required to exceed the threshold of logogens corresponding to high- than low-frequency words.

In the original logogen model, word recognition is

depicted as being "passive" in that the accumulation of evidence by logogens is presumed not to require attention (Morton, 1969). This assumption is clearly challenged by the results of the present research which show that lexical access requires attention. However, the original logogen model has undergone several changes which may allow it to include attentional processes. One possibility, suggested by Morton (1982), is that word recognition is not based on activation in the logogen system, but on "the operations of processes in the cognitive system". In this view, the word frequency effect is attributed to "the nature of semantic and associative components in the cognitive system". Accordingly, recognition may vary with word frequency because high-frequency words have "stronger and richer associations" than low-frequency words. Attention demands of word recognition are also assumed to be located in the cognitive system. Although Morton (1982) does not explicitly outline attention demands in the cognitive system, presumably the assumption could be made that attention is required for a shorter period of time to recognize low-frequency as compared to high-frequency words.

The validity of assigning attention demands to the cognitive system is difficult to evaluate because of the

vagueness of Morton's (1982) description of information transfer from the logogen system to the cognitive system and of events that take place within the cognitive system. In general, the contention is that the more "rich" the activation is in the cognitive system, the less the attention demands. Unfortunately, it is not entirely clear what is meant by "richness", nor is it immediately obvious how to test the hypothesis that richness of activation varies with word frequency. In addition to these difficulties, it is worth noting that Morton's approach is not consistent with a recent conceptualization of attention demands during reading (Britton, Glynn, Meyer, & Penland, 1982; Britton, Westbrook, & Holdredge, 1978).

In Britton's research (Britton, Glynn, Meyer, & Penland, 1982; Britton, Westbrook, & Holdredge, 1978), subjects read text while monitoring for an auditory probe. The type of text being read was varied from a narrative story to an expository text. Narrative stories were assumed to be simpler, more familiar, and more likely to activate story and knowledge schemata than expository text. In general, Britton found that responses to the auditory probe task were longer during concurrent reading of the narrative text as compared to when subjects were reading the expository text.

To account for this finding, Britton makes the assumption that activation of representations in memory takes capacity. Because activation is presumably greater during reading of the narrative than expository text, fewer resources are available for the probe task during concurrent processing of narrative stories.

Morton's (1982) notion of "richness" of activation in the cognitive system is similar to Britton's assumption of activation of knowledge schemata in memory and both researchers postulate that activation corresponds to capacity demand. However, the two approaches are clearly incongruent. Whereas Morton suggests that increases in activation reduces the demand for attentional capacity, Britton assumes that more activation results in more capacity demand. Therefore, Morton's conceptualization of attention demands in the cognitive system, including the primary assumption relating richness of activation to attention, is equivocal.

In summary, while the inclusion of attentional processes into verification models (Becker, 1976; Paap et al., 1982) adds to the utility of these approaches, Morton's (1969, 1970) original logogen model is inherently passive and thus is not amenable to the inclusion of attention. Modifications

of the original logogen model may allow for attentional processes. However, the cognitive based logogen model proposed by Morton (1982), is not described in sufficient detail to encourage informative investigation of attention demands. Moreover, the basic assumption relating richness of activation to attention in Morton's (1982) approach is incongruent with other approaches in which activation also plays a key role in attention demands (e.g., Britton, Glynn, Meyer, & Penland, 1982; Britton, Westbrook, & Holdredge, 1978). Therefore, it is important that more conceptual development is undertaken before attention demands in word recognition are examined within the context of a logogen based model.

Attention Demands of Word Recognition and Theories of Reading Skill

The primary purpose of the present research was to investigate the attention demands of word recognition. Therefore, it is beyond the intended scope of this thesis to provide a detailed analysis of attention demands in higher level tasks such as reading. However, because attention demands of word recognition have been identified as a potential source of individual differences in reading skill, the present research has direct implications for theories of

reading. One theory of reading ability that includes attention demands of word recognition as an important factor is Perfetti's verbal efficiency theory (Perfetti, 1985; Perfetti & Roth, 1981).

In Perfetti's verbal efficiency theory, individual differences in reading ability are related to the efficiency of the processes that are activated during reading, including lexical access. According to Perfetti, highly skilled readers have very efficient lexical access that requires only minimal attention. For these readers, there exists an abundance of resources available for input into other local processes such as encoding and integration of propositions (and potentially for completing higher level processes such as the making of inferences). With less skilled readers, however, lexical access requires a large amount of the total capacity, thereby leaving few resources to allocate towards other local processes.

In contrast to Perfetti's notion that lexical access requires capacity, it has been suggested that lexical processing is a likely candidate for automaticity (e.g., Curtis, 1980; LaBerge, 1973; Laberge & Samuels, 1974; Wolf, Bally, & Morris, 1986). In accord with an automaticity notion, the assumption that individual differences in

reading ability arise at the lexical level (Perfetti, 1985) would be violated. For example, because automatic processes are defined as not requiring attention, it is inconsistent to make the assumption that lexical access is automatic if it is also assumed that (a) lexical access requires attention and/or (b) that lexical access requires fewer resources in highly-skilled than in low-skilled readers.

As noted earlier, research in the Stroop literature has shown that word processing is automatic insofar as it occurs without intention. However, in contrast to the notion of automaticity, selected studies in the contextual priming (Parkin, 1979; see also Smith, 1979; Smith et al, 1983) and the Stroop (Kahneman & Chajczyk, 1983) literatures has shown that word processing is affected by attentional factors. Morover, dual-task studies have shown that reading interferes with performance on a secondary task (Britton, Glynn, Meyer, & Penland, 1982; Britton, Westbrook, & Holdredge, 1978). Therefore, there exists evidence across a variety of task domains suggesting that (a) reading is an attention demanding task, and (b) in accord with Perfetti (1985) some portion of the demands associated with reading are attributable to word processing. The present research adds to this literature by isolating the attention demands

associated with visual word recognition and by restricting the characterization of lexical access as a mandatory process.

An important question is whether word recognition can be more or less mandatory. That is, is it possible that recognition occurs without intention in both high-skill and low-skill readers, but that mandatory attention demands associated with recognition are greater in the low-skill reader? An interesting extension of the present research, therefore, would be to relate the attention demands of word recognition to individual differences in reading skill.

Conclusions

The present research shows that recognition of visually presented words demands attention and that these demands last longer during processing of low-frequency than high-frequency words. These findings are consistent with Becker's verification model (Becker, 1976, 1980, 1985; Becker & Killion, 1977; Eisenberg & Becker, 1982) in which each verification cycle is presumed to require a certain amount of attention. Further research into the attention demands of word recognition may capitalize on the extensive literature concerned with contextual priming. In this view, the verification model provides a strong framework which is

particularly suited for investigations of attention demands in contextual priming.

The verification model does not include provision for demands of lower level processes such as letter encoding. Insofar as letter encoding may be a integral part of word recognition (Paap et al., 1982), and insofar as letter encoding demands attention (Paap & Odgen, 1981), the verification model provides an incomplete account of attention demands in word recognition. In this view, the activation-verification model forwarded by Paap et al. (1982) is capable of including Becker's (1976) notion of attention demands during verification as well as providing a framework for investigating demands of lower level encoding processes during word recognition.

At the present time, direct access approaches, such as Morton's logogen model (Morton, 1969, 1970, 1979, 1982; Morton & Patterson, 1980), are ambiguous with respect to the attention demands of word recognition. Based on the growing body of research showing that word processing demands attention, it is clear that direct access models of word recognition need to be adapted to include attentional properties. It is not clear, however, if and how these models can be changed without violating the fundamental and

defining properties of these models (Morton, 1982).

Future investigations of attention demands during word processing should not be restricted to research paradigms in the word recognition area. Indeed, a very exciting, and unexplored area of research is that concerned with the attentional properties of the constituent processes underlying skilled reading. A useful starting point in this research domain would be to establish the relationship between the attention demands of word recognition and reading skill.

TABLES

Table 1

Mean Correct Detection, Movement and Total Latencies (in ms) to Auditory Probes: Experiments 1 and 2

	Measure								
	Detection			Movement			Total		
	Single	Dual		Single	Dual		Single	Dual	
SOA		HF	LF		HF	LF		HF	LF
				Experiment 1					
0	276	359	366	243	308	287	519	667	653
167	247	302	331	261	340	320	508	642	651
				Experiment 2					
167	304	538	554	203	208	207	507	746	761

Note. Single refers to single-task trials; Dual is dual-task trials. HF refers to high-frequency trials and LF refers to low-frequency trials

Table 2

Mean Correct Lexical Decision Latencies (in ms): Experiment 1

	Condition			
	Single-task		Dual-task	
SOA	HF	LF	HF	LF
0	532	687	561	690
167	523	650	555	732
mean:	528	669	558	711

Note. HF = high-frequency trials; LF = low-frequency trials.

Table 3

Mean Correct Detection, Movement and Total Latencies (in ms) To Auditory Probes: Experiment 3

	Measure								
	Detection			Movement			Total		
	Single	Dual		Single	Dual		Single	Dual	
Task		HF	LF		HF	LF		HF	LF
S	257	283	310	253	374	331	510	657	641
C	335	356	425	283	422	365	618	770	790

Note. S refers to simple-probe and C refers to complex-probe. Single and Dual refer to single-task and dual-task conditions, respectively. HF = high-frequency and LF = low-frequency trials.

Table 4

Mean Correct Lexical Decision Latencies (in ms): Experiment 3

	Condition			
	Single-task		Dual-task	
Task	HF	LF	HF	LF
Simple	517	629	571	683
Choice	543	634	586	729

Note. HF and LF refer to high- and low-frequency trials, respectively

Table 5

Mean Correct Detection, Movement and Total Latencies (in ms) To Auditory Probes: Experiment 4

Measure								
Detection			Movement			Total		
Single	Dual		Single	Dual		Single	Dual	
	HF	LF		HF	LF		HF	LF
338	412	436	277	306	299	615	718	735

Note. Single and Dual refer to single-task and dual-task conditions, respectively. HF = high-frequency and LF = low-frequency trials.

Table 6

Mean Correct Pronunciation Latencies (in ms): Experiment 4

Condition			
Single-task		Dual-task	
HF	LF	HF	LF
575	616	689	727

Note. HF and LF refer to high- and low-frequency trials, respectively

Table 7

Mean Correct Detection, Movement and Total Latencies (in ms) To Auditory Probes: Experiment 5

	Measure								
	Detection			Movement			Total		
	Single	Dual		Single	Dual		Single	Dual	
Task		HF	LF		HF	LF		HF	LF
Easy	378	441	459	302	278	283	680	719	742
Hard	446	513	527	329	301	309	775	814	836

Note. Easy refers to easy-probe and hard refers to hard-probe task. Single and Dual refer to single-task and dual-task conditions, respectively. HF = high-frequency and LF = low-frequency trials.

Table 8

Mean Correct Pronunciation Latencies (in ms): Experiment 5

	Condition			
	Single-task		Dual-task	
Task	HF	LF	HF	LF
Easy	603	649	763	795
Hard	579	625	809	800

Note. HF and LF refer to high- and low-frequency trials, respectively

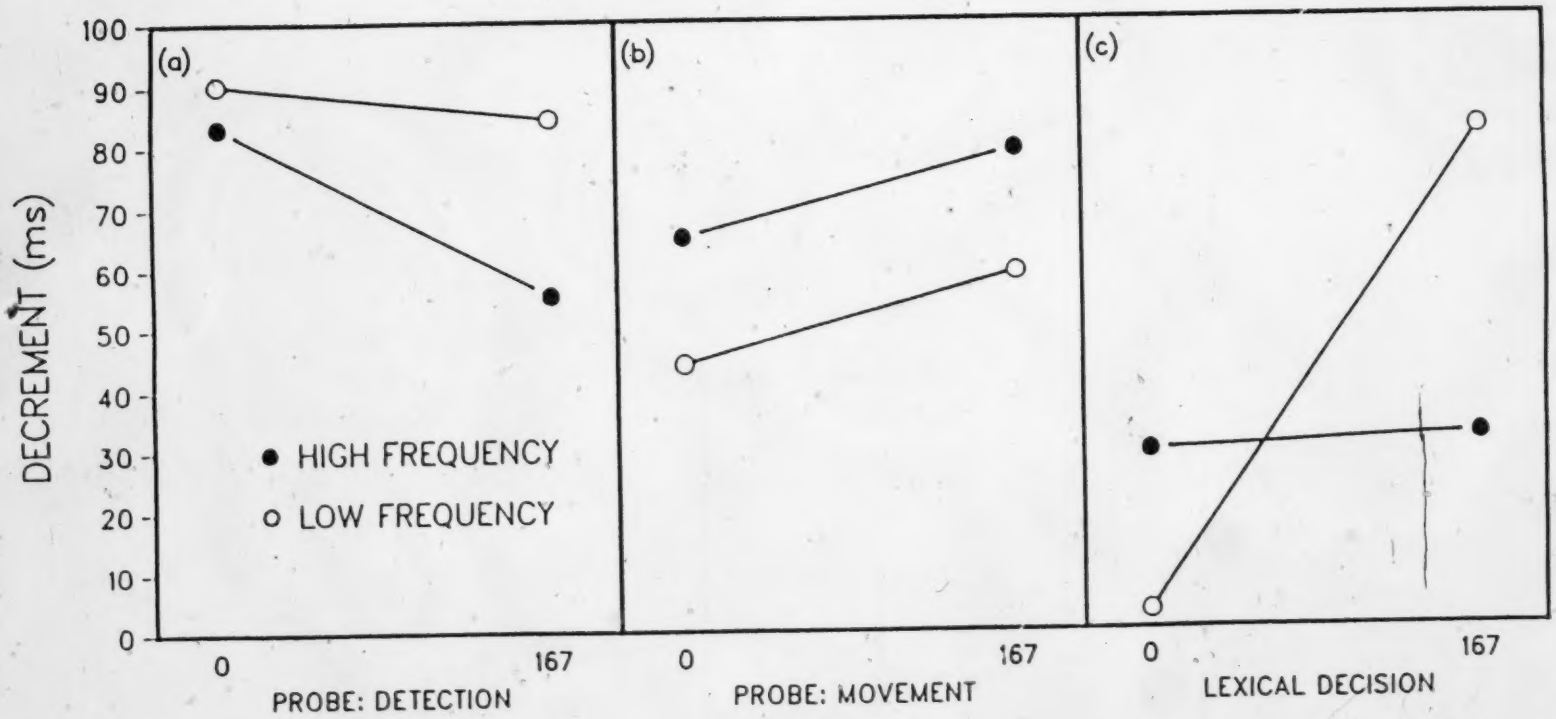


Figure 1. Experiment 1. Single- to Dual-task Decrements on the Probe Task.

REFERENCES

Baddeley, A., Logie, R., Nimmo-Smith, I., & Brereton, N. (1985). Components of fluent reading. Journal of Memory and Language, 24, 119-131.

Balota, D. A., & Chumbley, J. L. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. Journal of Experimental Psychology: Human Perception and Performance, 10, 340-357.

Balota, D. A., & Chumbley, J. L. (1985). The locus of word-frequency effects in the pronunciation task Lexical access and/or production? Journal of Memory and Language, 24, 89-106.

Becker, C. A. (1976). Allocation of attention during visual word recognition. Journal of Experimental Psychology: Human Perception and Performance, 2, 556-566

Becker, C. A. (1979). Semantic context and word frequency effects in visual word recognition. Journal of Experimental Psychology: Human Perception and Performance, 5, 252-259.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. Memory and Cognition, 8, 493-512.

Becker, C. A. (1985). What do we really know about semantic context effects during reading? In D. Besner, T.G. Waller, & G.E. MacKinnon (Eds.), Reading research: Advances in theory and practice V, (pp. 125-169). Orlando Florida: Academic Press, Inc.

Becker, C. A., & Killion, T. H. (1977). Interaction of visual and cognitve effects in word recognition. Journal of Experimental Psychology: Human Perception and Performance, 3, 389-401.

Besner, D., & Swan, M. (1982). Models of lexical access in visual word recognition. Quarterly Journal of Experimental Psychology, 34A, 313-325.

Britton, B. K., Glynn, S. M., Meyer, B. J. F., & Penland, M. J. (1982). Effects of text structure on use of cognitive capacity during reading. Journal of Educational Psychology, 74, 51-61.

Britton, B. K., Westbrook, R. D., & Holdredge, T. S. (1978). Reading and cognitive capacity usage: Effects of text difficulty. Journal of Experimental Psychology: Human Learning and Memory, 4, 582-591.

Broadbent, D. E. (1982). Task combinations and selective intake of information. Acta Psychologia, 50, 253-290.

Carr, T. H., & Pollatsek, A. (1985). Recognizing printed words: A look at current models. In In D. Besner, T.G. Waller, & G.E. MacKinnon (Eds.), Reading research: Advances in theory and practice V (pp. 1-82). Orlando Florida: Academic Press, Inc.

Chumbley, J. L., & Balota, D. A. (1984). A word's meaning affects the decision in lexical decision. Memory and Cognition, 12, 590-606.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic memory. Pscyhological Review, 83, 407-428.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), Strategies of information processing (pp. 151-216). London: Academic Press.

Coltheart, M., Davelaar, E., Jonasson, J., & Besner, D., (1977). Access to the internal lexicon. In S. Dornic (Ed.), Attention and performance VI (pp. 535-555). Hillsdale, NJ:Erlbaum.

Curtis, M. E. (1980). Development of components of reading skill. Journal of Educational Psychology, 72, 656-669.

De Groot, A. M. B., Thomassen, A. J. W. M., Hudson, P. T. W. (1982). Associative facilitation of word recognition as measured from a neutral prime. Memory and Cognition, 10, 358-370.

den Heyer, K. (1986). Manipulating attention-induced

priming in a lexical decision task by means of repeated prime-target presentations. Journal of Memory and Language, 25, 19-42.

den Heyer, K., Briand, K., & Dannenbring, G. L. (1983). Strategic factors in a lexical decision task: Evidence for automatic and attention-driven processes. Memory and Cognition, 11, 374-381.

Dobbs, A. R., Friedman, A., & Lloyd, J. (1985). Frequency effects in lexical decisions: A test of the verification model. Journal of Experimental Psychology: Human Perception and Performance, 11, 81-92.

Dyer, F. H. (1973). The Stroop phenomenon and its use in the study of perceptual, cognitive and response processes. Memory and Cognition, 1, 106-120.

Eisenberg, P., & Becker, C. A. (1982). Semantic context effects in visual word recognition, sentence processing, and reading: Evidence for semantic strategies. Journal of Experimental Psychology: Human Perception and Performance, 8, 739-756.

Fischler, I. (1977a). Sematic facilitation without association in a lexical decision task. Memory and Cognition, 5, 335-339

Fischler, I. (1977b). Associative facilitation without expectancy in a lexical decision task. Journal of Experimental Psychology: Human Perception and Performance, 3, 18-26.

Fischler, I., & Bloom, P. A. (1979). Automatic and attentional processes in the effects of sentence context on word recognition. Journal of Verbal Learning and Verbal Behavior, 18, 1-20.

Fischler, I., & Goodman, G. O. (1978). Latency of associative activation in memory. Journal of Experimental Psychology: Human Perception and Performance, 4, 455-470.

Forster, K. I. (1976). Accessing the mental lexicon. In R. J. Wales & E. C. T. Walker (Eds.), New approaches to

language mechanisms. Amsterdam:North Holland.

Frederiksen, J. R. (1978). Assessment of perceptual, decoding and lexical skills and their relation to reading proficiency. In A. Lesgold, J. W. Pellegrino, S. D. Fokkema, & R. Glaser (Eds.), Cognitive psychology and instruction (pp. 153-169). New York: Plenum.

Frederiksen, J. R. (1981). Sources of process interactions in reading. In A. M. Lesgold & C. A. Perfetti (Eds.), Interactive processes in reading (pp. 361-386). Hillsdale, NJ: Erlbaum.

Frederikson, J. R. (1982). A componential theory of reading skills and their interactions. In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence (pp. 124-180). Hillsdale, NJ: Lawrence Erlbaum.

Glushko, R. J. (1979). The organization and activation of orthographic knowledge in reading aloud. Journal of Experimental Psychology: Human Perception and Performance, 5, 674-691.

Gopher, D., & Navon, D. (1980). How is performance limited: Testing the notion of central capacity. Acta Psychologia, 46, 161-180.

Gordon, B. (1983). Lexical access and lexical decisions: Mechanisms of frequency sensitivity. Journal of Verbal Learning and Verbal Behavior, 22, 24-44.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, 356-388.

Herdman, C. M., & Friedman, A. (1985). Multiple resources in divided attention: A cross-model test of the independence of hemispheric resources. Journal of Experimental Psychology: Human Perception and Performance, 11, 40-49.

Hirst, E. S., Spelke, C. C., Reaves, G., Caharack, G., & Neisser, U. (1980). Dividing attention without alternation or automaticity. Journal of Experimental Psychology: General, 109, 98-117.

Humphreys, G. W. (1985). Attention, automaticity, and autonomy in visual word processing. In D. Besner, T.G. Waller, & G.E. MacKinnon (Eds.), Reading research: Advances in theory and practice V, (pp. 253-310). Orlando Florida: Academic Press, Inc.

Hogaboam, T. W., & Pellegrino, J. W. (1978). Hunting for individual differences in cognitive processes: Verbal ability and semantic processing of pictures and words. Memory and Cognition, 6, 189-193.

Hogaboam, T. W., & Perfetti, C. A. (1978). Reading skill and the role of verbal experience in decoding. Journal of Educational Psychology, 70, 717-729.

Johnson, P. J., Forester, R. A., Calderwood, R., & Weisgerber, S. A. (1983). Resource allocation and the attentional demands of letter encoding. Journal of Experimental Psychology: General, 112, 616-638.

Kahneman, D. (1973). Attention and Effort. Englewood Cliffs, NJ: Prentice-Hall.

Kahneman, D., & Chajczyk, D. (1983). Tests of the automaticity of reading: Dilution of Stroop effects by color-irrelevant stimuli. Journal of Experimental Psychology: Human Perception and Performance, 9, 497-509.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), Perceptual Organization. Hillsdale, NJ: Erlbaum.

Karlin, L., & Kestenbaum, R. (1968). Effects of number of alternations on the psychological refractory period. Quarterly Journal of Experimental Psychology, 20, 167-178.

Keele, S. W. (1973). Attention and human performance. Pacific Palisades, CA :Goodyear

Kerr, B. (1973). Processing demands during mental operations. Memory and Cognition, 3, 653-664.

Kucera, H., & Francis, W. N. (1967). Computational analysis of present-day American English. Providence, RI: Brown University Press.

LaBerge, D. (1973). Attention and the measurement of perceptual learning. Memory and Cognition, 1, 268-276.

LaBerge, D. (1975). Acquisition of automatic processing of perceptual and associative learning. In P. M. A. Rabbitt & S. Dornic (Eds.), Attention and Performance V. New York: Academic Press.

LaBerge, D. (1981). Automatic information processing: A review. In J. Long & A. Baddeley (Eds.), Attention and Performance IX (pp. 173-186). Hillsdale NJ: Erlbaum.

LaBerge, D., & Samuels, S.J. (1974). Toward a theory of automatic information processing in reading. Cognitive Psychology, 6, 293-323.

Larochelle, S., McClelland, J. L., Rodriguez, E. (1980). Context and the allocation of resources in word recognition. Journal of Experimental Psychology: Human Perception and Performance, 6, 686-694.

Logan, G. D. (1979). On the use of concurrent memory load to measure attention and automaticity. Journal of Experimental Psychology: Human Perception and Performance, 5, 189-207.

Logan, G. D. (1980). Attention and automaticity in Stroop and priming tasks: Theory and data. Cognitive Psychology, 12, 523-553.

Logan, G. D. (1983). On the ability to inhibit simple thoughts and actions: I. Stop-signal studies of decision and memory. Journal of Experimental Psychology: Learning, Memory and Cognition, 9, 585-606.

Logan, G. D. (1985). On the ability to inhibit simple thoughts and actions: II. Stop-signal studies of repetition priming. Journal of Experimental Psychology: Learning, Memory and Cognition, 11, 675-691.

Logan, G. D., & Burkell, J. (1986). Dependence and

independence in responding to double stimulation: A comparison of stop, change, and dual-task paradigms. Journal of Experimental Psychology: Human Perception and Performance, 12, 549-563.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. Psychological Review, 91, 295-327.

Lorch, R. F. (1982). Priming and search processes in semantic memory: A test of three models of spreading activation. Journal of Verbal Learning and Verbal Behavior, 21, 468-492.

Lorch, R. F., Balota, D. A., & Stamm, E. G. (1986). Locus of inhibition effects in the priming of lexical decisions: Pre- or postlexical access? Memory and Cognition, 14, 95-103.

Lowe, D. C., & Mitterer, J. O. (1982). Selective divided attention in a Stroop task. Canadian Journal of Psychology, 36, 684-700.

Massaro, D. W. (1979). Letter information and orthographic context in word preception. Journal of Experimental Psychology: Human Perception and Performance, 5, 595-609.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. Psychological Review, 88, 375-407.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology, 90, 227-234.

Morton, J. (1969). Interaction of information in word recognition. Psychological Review, 76, 165-178.

Morton, J. (1970). A functional model of memory. In D. A. Norman (Ed.), Models of human memory. New York: Academic Press.

Morton, J. (1979). Facilitation in word recognition: Experiments causing changes in the logogen model. In P. A. Kolers, M. E. Wrolstad, & H. Bouma (Eds.), Processing Visible Language 1 (pp.259-269). New York: Plenum Press.

Morton, J. (1982). Disintegrating the lexicon: An information processing approach. In J. Mehler, E. C. T. Walker, & M. Garrett (Eds.), Perspectives on mental representation (pp.89-109). Hillsdale, NJ: Erlbaum.

Morton, J., & Patterson, K. (1980). A new attempt at an interpretation, or an attempt at a new interpretation. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), Deep dyslexia (pp. 91-118). London: Routledge & Kegan Paul.

Navon, D., & Gopher, D. (1979). On the economy of the human information-processing system. Psychological Review, 86, 214-255.

Navon, D., & Gopher, D. (1980). Task difficulty, resources, and dual-task performance. In R. S. Nickerson (Ed.), Attention and performance VIII (pp. 297-318). Hillsdale, NJ: Erlbaum.

Neely, J. H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. Memory and Cognition, 4, 648-654.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. Journal of Experimental Psychology: General, 106, 226-254.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Odgen, W. C., Martin, D. W., & Paap, K. R. (1980). Processing demands of encoding: What does secondary task performance reflect? Journal of Experimental Psychology: Human Perception and Performance, 6, 355-367.

Paap, K. R., Newsome, S. L., McDonald, J. E., &

Schvaneveldt, R. W. (1982). An actication-verification model for letter and word recognition: The word-superiority effect. Psychological Review, 89, 275-280.

Paap, K. R., & Odgen, W. C. (1981). Letter encoding is an obligatory but capacity demanding operation. Journal of Experimental Psychology: Human Perception and Performance, 7, 518-527.

Palmer, J., Macleod, C. M., Hunt, E., & Davidson, J. (1985). Information processing correlates of reading. Journal of Memory and Language, 24, 59-88.

Parkin, A. J. (1979). Specifiying levels of processing. Quarterly Journal of Experimental Psychology, 31, 179-195.

Perfetti, C. A. (1985). Reading Ability. New York, NY: Oxford University Press.

Perfetti, C. A. & Lesgold, A. M. (1979). Coding and comprehension in skilled reading and implications for reading instructions. In L. B. Resnick & P. A. Weaver (Eds.), Theory and practice of early reading (Vol. 1.) Hillsdale, NJ: Lawrence Erlbaum.

Perfetti, C. A., & Roth, S. F. (1981). Some of the interactive processes in reading and their role in reading skill. In A. M. Lesgold & C. A. Perfetti (Eds.), Interactive processes in reading (pp. 269-298). Hillsdale, NJ: Erlbaum.

Posner, M. I. (1978). Chronometric explorations of mind. Hillsdale, NJ: Erlbaum.

Posner, M. I., & Boies, S. J. (1971). Components of attention. Psychological Review, 78, 391-408.

Posner, M. I., & Klein, R. (1973). On the function of consciousness. In S. Kornblum (Ed.), Attention and Performance IV (pp. 21-35). New York: Academic Press.

Posner, M. I., & Snyder, C. R. R. (1975a). Attention and cognitive control. In R. L. Solso (Ed.), Information

processing and cognition: The Loyola symposium (pp. 55-85). Hillsdale, NJ: Erlbaum.

Posner, M. I., & Snyder, C. R. R. (1975b). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt, & S. Dornic (Eds.), Attention and Performance V (pp. 669-682). New York:Academic Press.

Proctor, R. W. (1978). Attention and modality specific interference in visual short-term memory. Journal of Experimental Psychology: Human Learning and Memory, 4, 239-245.

Proctor, R. W., & Proctor, J. D. (1979). Secondary task modality, expectancy, and the measurement of attentional capacity. Journal of Experimental Psychology: Human Perception and Performance, 5, 549-563.

Ratcliff, R., & McKoon, G. (1981a). Automatic and strategic priming in recognition. Journal of Verbal Learning and Verbal Behavior, 20, 204-215.

Ratcliff, R., & McKoon, G. (1981b). Does activation really spread? Psychological Review, 20, 204-215.

Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: Part 2. The contextual enhancement effect and some tests and extensions of the model. Psychological Review, 89, 60-94.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. Journal of Experimental Psychology: Human Perception and Performance, 3, 1-17.

Scarborough, D. L., Gerard, L., & Cortese, C. (1979). Accessing lexical memory: The transfer of word repetition effects across task and modality. Memory and Cognition, 7, 3-12.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic information processing: I. Detection, search and attention. Psychological Review, 84, 1-66.

Schvaneveldt, R. W., & McDonald, J. E. (1981). Semantic context and the encoding of words: Evidence for two modes of stimulus analysis. Journal of Experimental Psychology: Human Perception and Performance, 7, 673-687.

Seidenberg, M. S., Waters, G. S., Sanders, M., & Langer, P. (1984). Pre- and postlexical loci of contextual effects on word recognition. Memory amd Cognition, 12, 315-328.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. Psychological Review, 84, 127-190.

Smith, M. C. (1979). Contextual facilitation in a letter search task depends on how the prime is processed. Journal of Experimental Psychology: Human Perception and Performance, 5, 239-251.

Smith, M. C., Theodor, L., & Franklin, P. E. (1983). The relationship between contextual facilitation and depth of processing. Journal of Experimental Psychology: Learning, Memory and Cognition, 9, 697-712.

Stanners, R. F., & Forbach, G. B. (1973). Analysis of letter strings in word recognition. Journal of Experimental Psychology, 98, 31-35.

Stanovich, K. E. (1980). Toward and interactive model of individual differences in the development of reading fluency. Reading Research Quarterly, 16, 32-71.

Stanovich, K. E. (1981). Attentional and automatic context effects in reading. In A. M. Lesgold & C. A. Perfetti (Eds.), Interactive Processes in Reading (pp. 241-268). Hillsdale, NJ: Erlbaum.

Stanovich. K. E., & West. R. F. (1979). Mechanisms of sentence context effects in reading: Automatic activation and conscious attention. Memory and Cognition, 7, 77-85.

Stanovich, K. E., & West, R. F. (1981). The effect of sentence context on ongoing word recognition: Tests of a

two-process theory. Journal of Experimental Psychology: Human Perception and Performance, 7, 658-672.

Stanovich, K. E., & West, R. F. (1983). On priming a sentence context. Journal of Experimental Psychology: General, 112, 1-36.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, 643-661.

Tweedy, J. R., & Lapinski, R. H. (1981). Facilitating word recognition: Evidence for strategic and automatic factors. Quarterly Journal of Experimental Psychology, 33A, 51-59.

Tweedy, J. R., Lapinski, R. H., & Schvaneveldt, R. W. (1977). Semantic-context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. Memory and Cognition, 5, 84-89.

Waters, G. S., & Seidenberg, M. S. (1985). Spelling-sound effects in reading: Time course and decision criteria. Memory and Cognition, 13, 557-572.

Whaley, C. P. (1978). Word - nonword classification time. Journal of Verbal Learning and Verbal Behavior, 17, 143-154.

Wolf, M., Bally, H., & Morris, R. (1986). Automaticity, retrieval processes, and reading: A longitudinal study in average and impaired readers. Child Development, 57, 988-1000.